ENERGY LIMITED COMMUNICATIONS IN HARVESTER ASSISTED WIRELESS SENSOR NODES

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ISOCS Winter School 2023

Outline

- Autonomous wireless sensor nodes in IoT.
- Power limited VS Energy limited scenarios.
- Key aspect of energy limited systems.
  - Communication protocols.
  - Sensors.
  - Power generators and Energy Management.
- Summary and future challenges.

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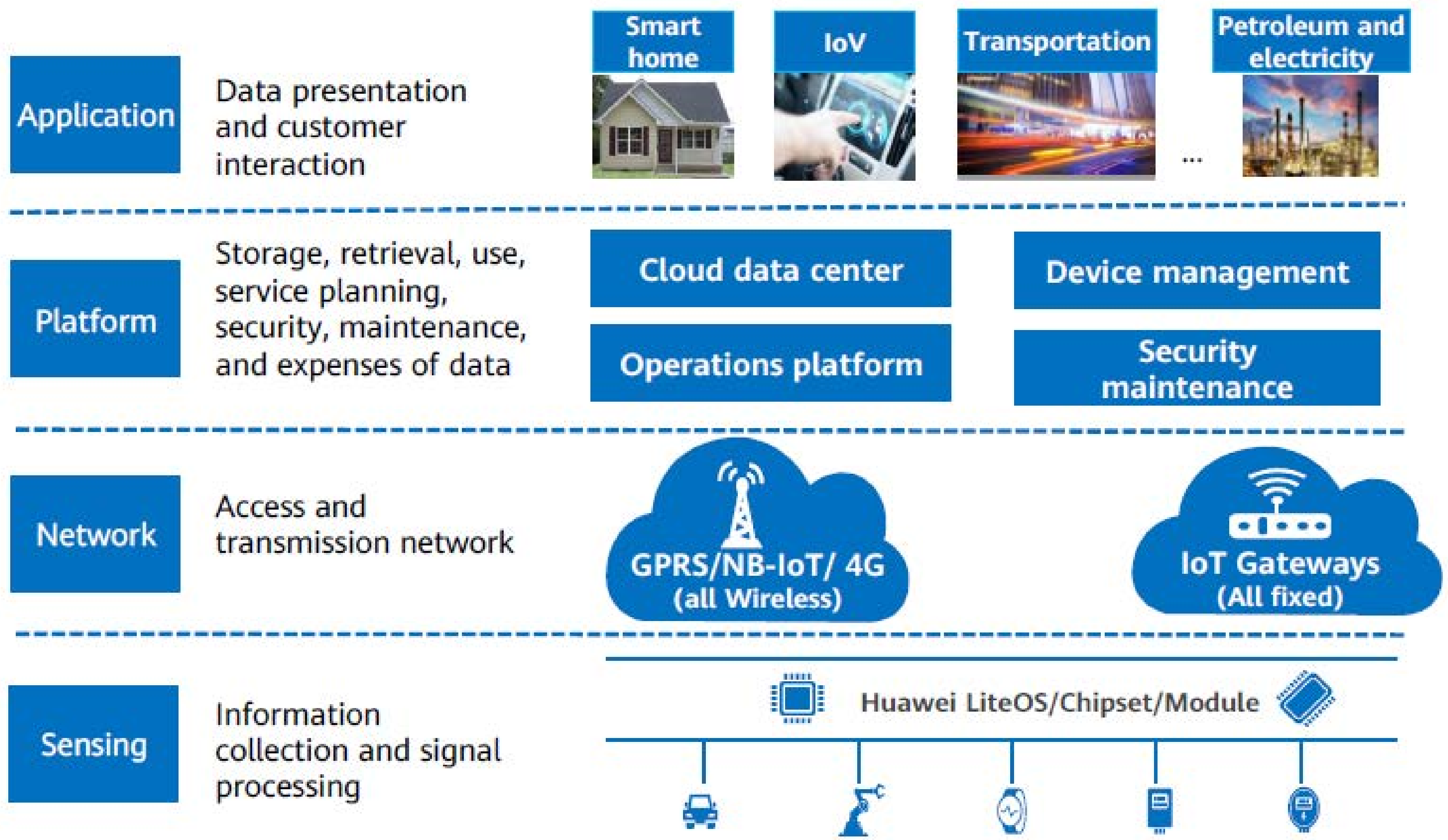
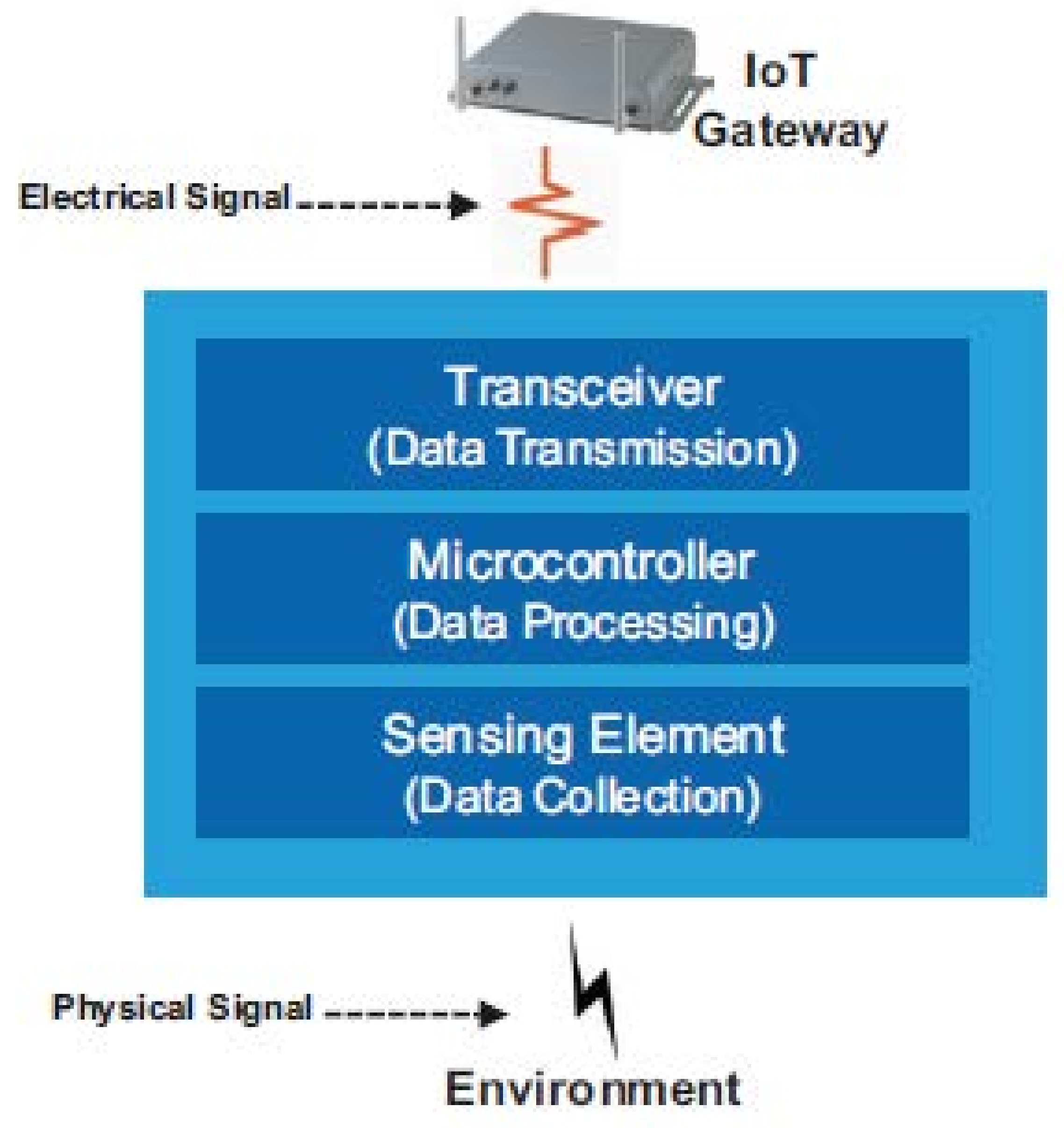
Autonomous Wireless Sensor Nodes
IoT Architecture



- IoT technology offers a structure based on layers to make available a huge amount of data generated by "things" in the Internet.
- Many vendors are taking strategical positions specially at application, platform and network layers.
- Sensing layer is the limiting factor in many use cases

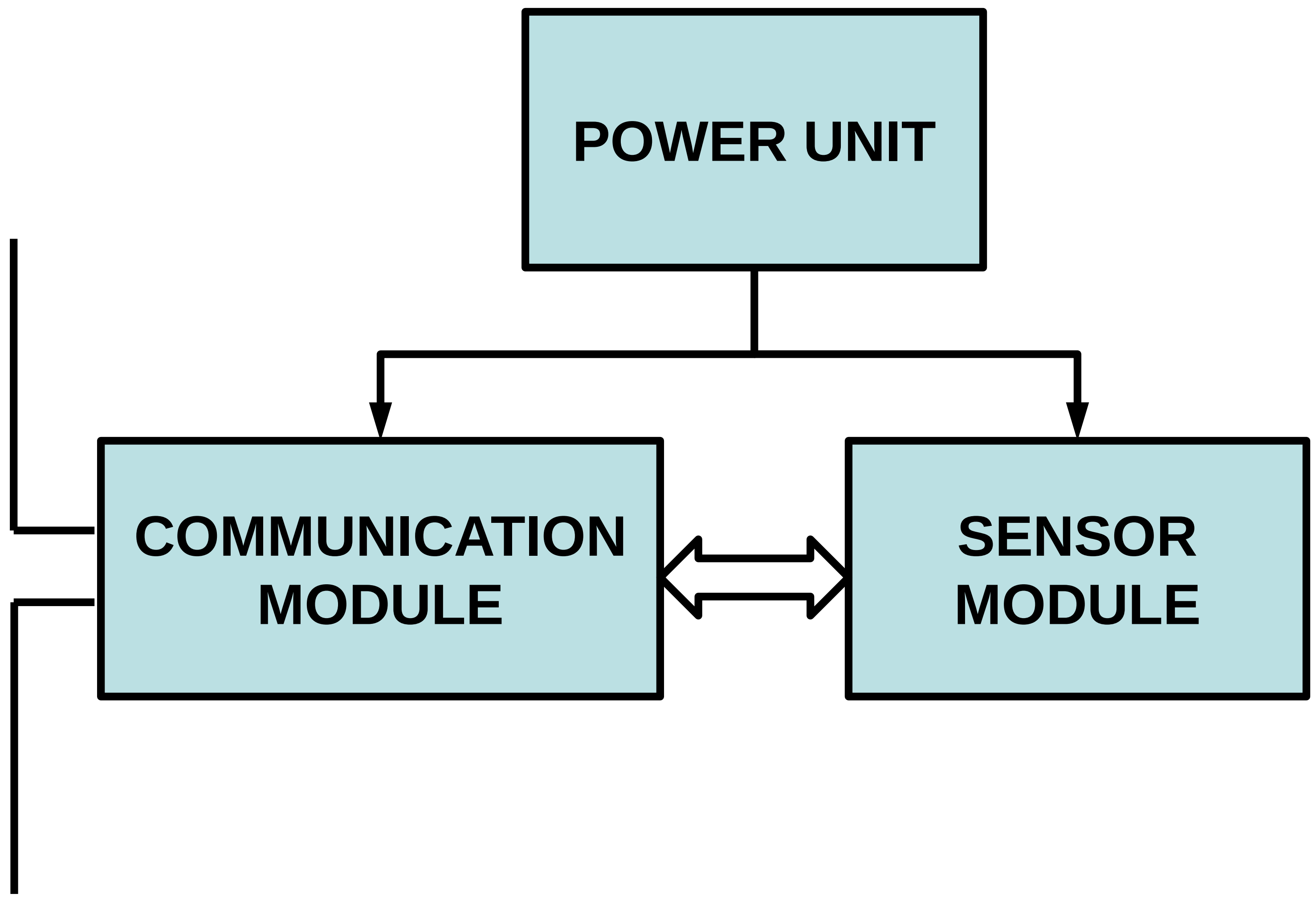
Autonomous Wireless Sensor Nodes
Sensor Layer

- AWSN: Sensor devices without physical connection to any network.
- Functions:
  - Convert an environmental magnitude into electrical signal.
  - Process/calibrate the measured signal.
  - Communicate with the network wirelessly.
- Ideal characteristics:
  - Accurate.
  - Light.
  - Cheap (BOM and maintenance cost)
  - Secure (from com point of view).
  - Large communication range.
  - Easy to install.



Autonomous Wireless Sensor Nodes Block description

- Very clear functional block description:



Ideal characteristics:

Accurate.
Light.
Cheap
Secure.
Portable.
Easy to install.
Sustainability

- As it is independent from the wired power supply, a battery is usually the solution. Which are the limitations of small batteries?

Autonomous Wireless Sensor Nodes
IoT current consumption

- Current consumption of ultra-low power IoT electronic modules.

Device	Type	I_Q	I_{ACTV}
HDC1080	Digital Humidity Sensor	100 nA	710 nA
LMT70	Analog Temperature Sensor	50 nA	9.2 µA
MSP430F1491	Ultra-low-power mixed-signal µCU	1.6 µA	280 µA (at 1 MHz)
CC3120	Wi-Fi Wireless Network Processor	4.5 µA	59 mA/229 mA (RX/TX)
XB24-AWI-001	Zigbee RF Module	3 µA	31 mA / 45 mA (RX/TX)
ADS1113	I^2C-compatible 16-bit ADC	500 nA	150 µA
LPV542	Dual CMOS Op Amp	490 nA(per channel)	N.A.
LP5907	Low-I_Q Linear Regulator	200 nA	250 µA

- Around 3uA of quiescent current consumption.
- More than 30mA if the communication module is listening to the network (can be reduced depending on the protocol).

Autonomous Wireless Sensor Nodes
Battery life

- CR1025: A Battery that does not compromise cost/weigth/size:
  - 10mm diameter x 2.5mm thickness
  - 0.2 €
  - 30mAh

- Considering a 3uA current consumption:
  - CR1025 30mAh @3.0V
  - 30mAh=3uA1000h
  - 1000h=41,6 days

- Not valid from a sustainability, maintenance cost and performance point of view.

Autonomous Wireless Sensor Nodes
Sensor Layer

- We may increase the battery life using different techniques:
  - Increase the battery size. (cost, weight and sustainability problem)
    - Iphone 1: 1500 mAh
    - iPhone 14 Pro Max: 4.323 mAh
  - Use rechargeable batteries (cost, weight and may not be feasible from application point of view)
    - Tuesday demo 4000mAh. 6€
  - Use harvesters to increase the battery life.
  - Use harvesters to eliminate the batteries

- When using harvesters it is key to know if they generate more average power than the consumed by the load.

Autonomous Wireless Sensor Nodes Harvester outputs

- Power density and voltage level outputs of different harvesters.

Energy Source	Power Density
Solar (outdoors sunny day)	$15\ mW/cm^2$
Solar (indoors)	$10\ \mu W/cm^2$
Vibration (human motion ~Hz)	$4\ \mu W/cm^3$
Vibration (machines ~KHz)	$800\ \mu W/cm^3$
Radiant RF (GSM)	$0.1\ \mu W/cm^2$
Radiant RF (WiFi)	$0.01\ \mu W/cm^2$
Push buttons	$50\ \mu J/N$
Thermoelectric (human body)	$40\ \mu W/cm^2$

Energy Source	Input Voltage (V)
Thermoelectric (TEG)	50 mV - 300 mV
Indoor photodiode	200 mV - 300 mV
Outdoor photodiode	300 mV - 450 mV
Indoor solar cell	500 mV - 800 mV
Outdoor solar cell	1.2V - 1.9V
Piezoelectric impact	AC attenuated pulse w/ peak @5-20V, 3 - 5 cycles and frequency 50 - 200Hz
Piezoelectric vibration	AC 1-3V
Triboelectric sliding	AC 600V - 1000V

- It is not easy to ensure that a reasonable size harvester can provide enough (average) power to a wireless sensor node load.

- On Tuesday Christian Bur said, “Before doing any calibration you need to know your target application”. In this case “Before eliminating the batteries you need to know your target application and your load behaviour”

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- **Power limited VS Energy limited scenarios.**

- Key aspect of energy limited systems.
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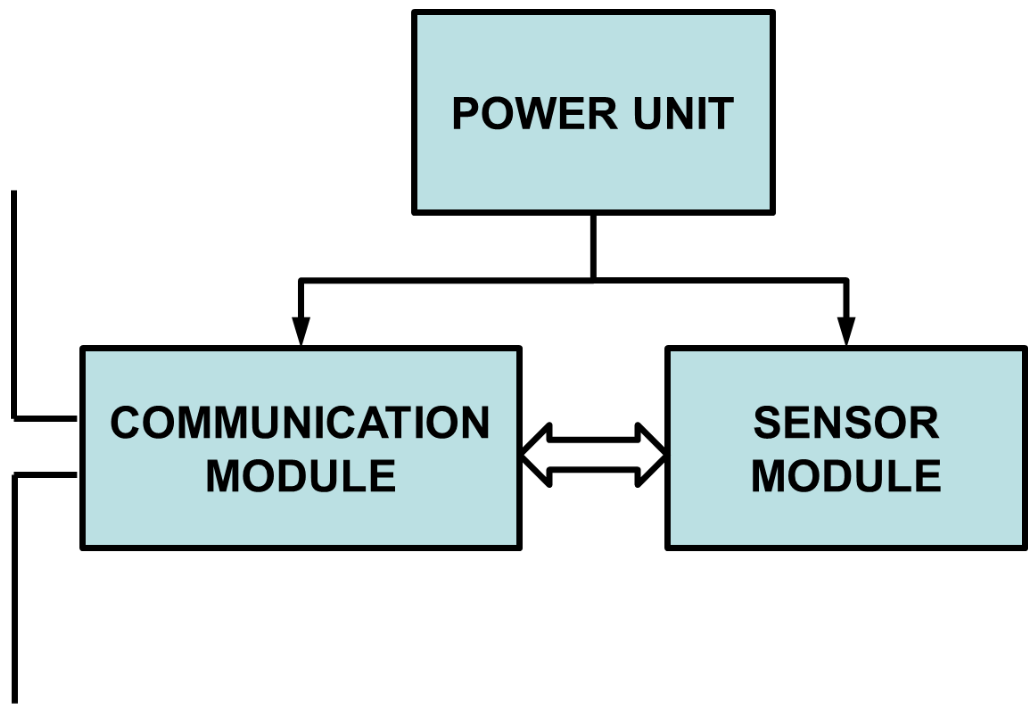
Power limited vs Energy limited.
Power limited

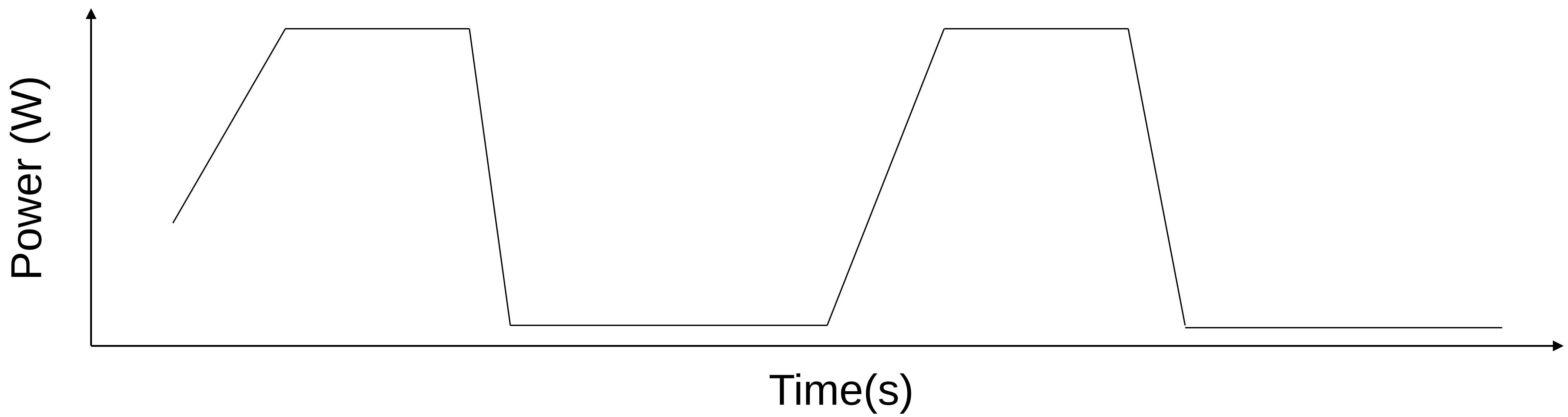
- Which are the power requirements of most of the low power wireless sensor nodes? Even the ones that are assisted with a power harvester?



- Usually the whole wireless sensor system is designed to minimize the (average) power consumption in order to increase the battery life, which is continuously supplying voltage to the circuit.
- **I call to this a power limited system.**

Power limited vs Energy limited. Power limited

- Circuits called "low energy" are planned to operate under this mode. Average energy is usually reduces using a duty cycle and different modes (idle state, for instance) during each of the cycles.



- During the "minimum power state" the system can do different tasks:
  - Be ready to receive messages from the network/reader
  - Run a real time clock to perform a duty cycled operation.
  - Do continuous measurements and enable a TX when an event occurs.

Power limited vs Energy limited. Power limited

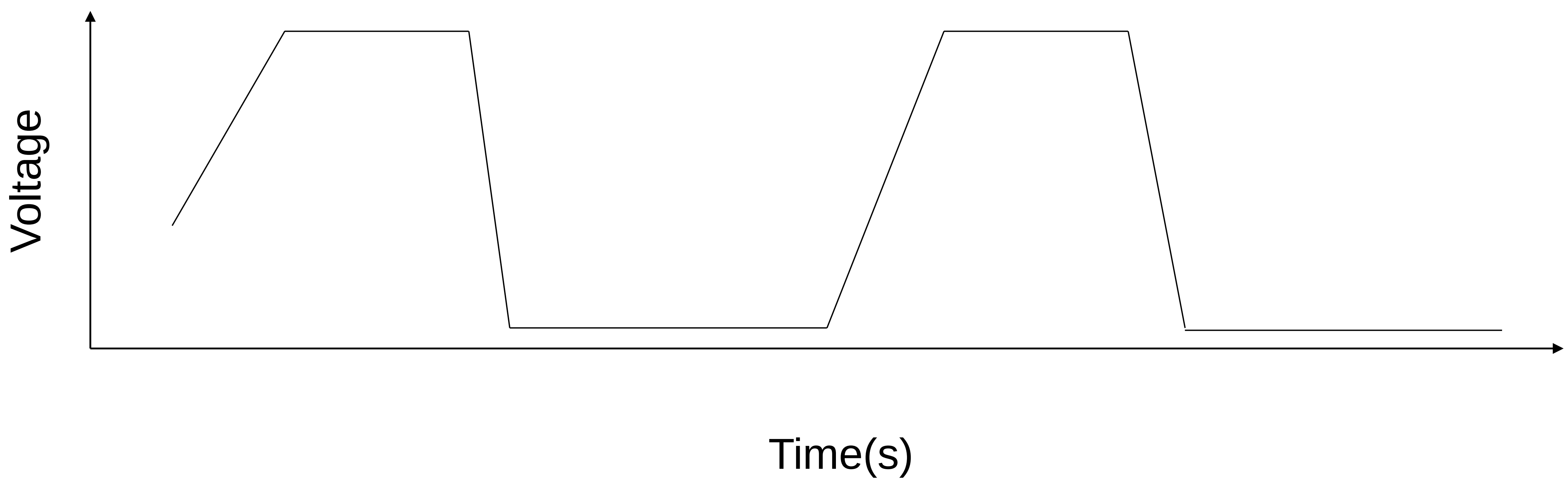
- Different energy sources can be considered in this power limited scenario:
  - Battery.
  - Rechargeable battery.
  - Harvester+battery.
  - **Harvester+<u>Capacitor.</u>**

- If it has an energy harvesting unit we must try to <u>maximize the average available power</u> at the desired operation voltage and over the different operation modes. MPPT, efficiency… are common terms.

- If the average power consumed by the load is above the power generated by the harvester a power limited load requires:
  - Backup battery is mandatory.
  - Energy limited system redesign.

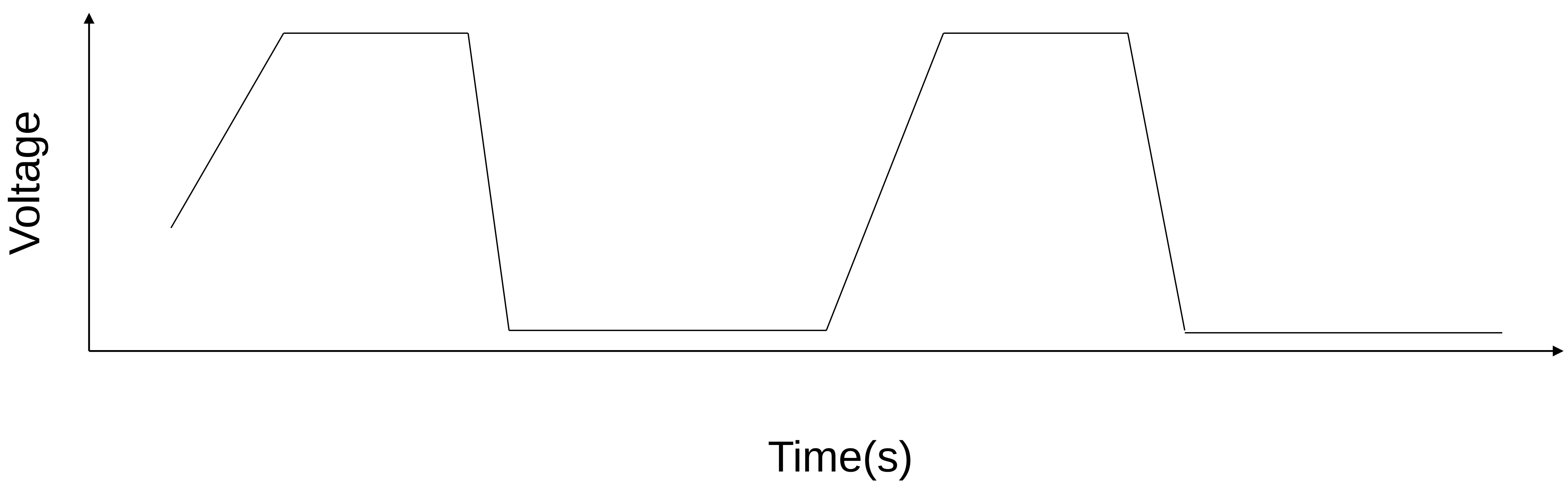
Power limited vs Energy limited. Energy limited

- When the average power harvested by the system is below the average required by the load we have a energy limited system.
- There is no stable voltage available continuously-> the harvesting source may be temporary missing or we totally consume every single joule in each transmission.
- The sensor node is switched on to perform an specific operation from time-to-time. Requires a specific time, with a specific average power consumption->specific energy budget.



Power limited vs Energy limited.
Energy limited

- The rest of the time the modules are switched off with, ideally, zero-power consumption and the system can load the supply capacitor using the harvester.
- There is no activity at the load during the recharge period.
- Regarding the harvester it is not a MPPT and efficiency problem but a capacitor charging (time) issue.

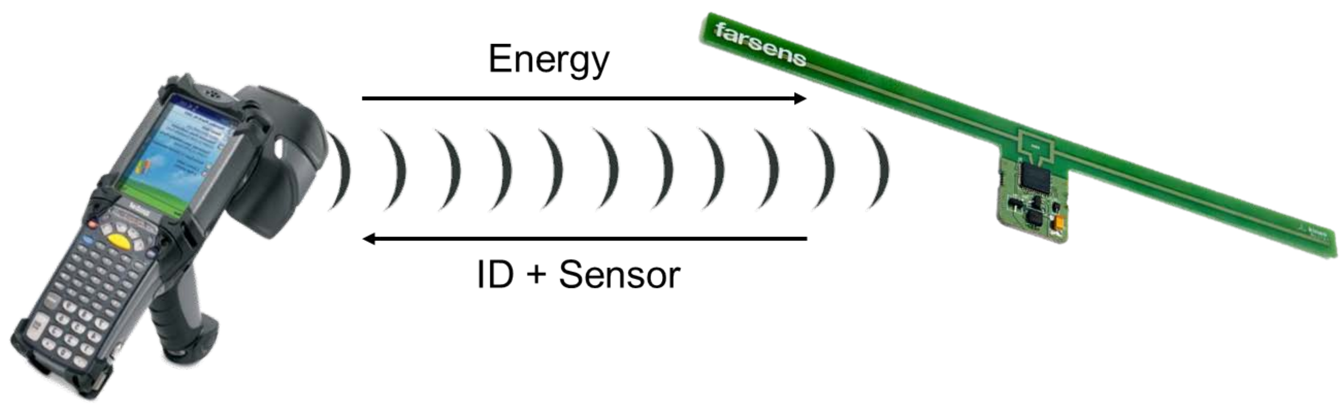


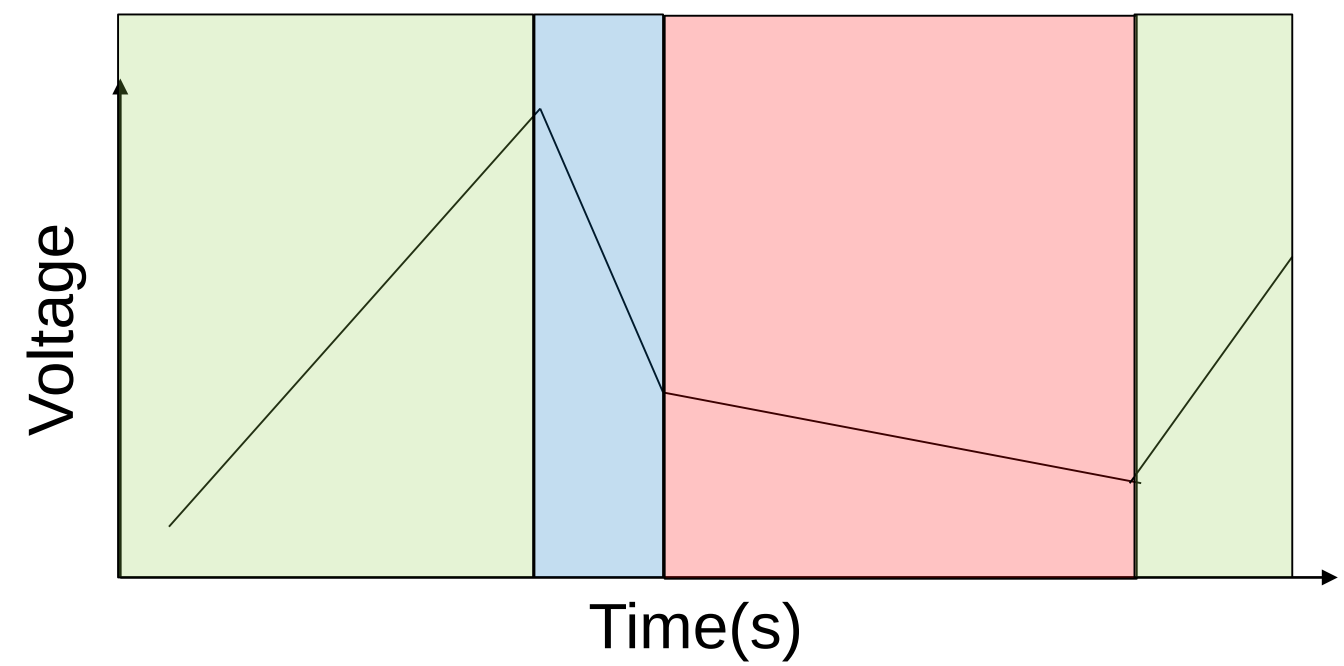
Power limited vs Energy limited. LORA example

- LoRaWAN is an ultra-long-range wireless transmissions solution based on spread spectrum technology.
- Very popular for IoT networks.
- The usual communication protocol requires bidirectional communications.
- Really low power consumption for a large communication range (up to km). Long communication time in order to reduce the power consumption. Probably best option in long-range power-limited communications, but not usually if the voltage is not continuous or energy is critical.

Power limited vs Energy limited. RFID SENSORS

- Whole system only enabled when reader generates request and RF field. Uses an RF energy harvester. 4-5 meters of range with sensor. 15 meters without sensor.

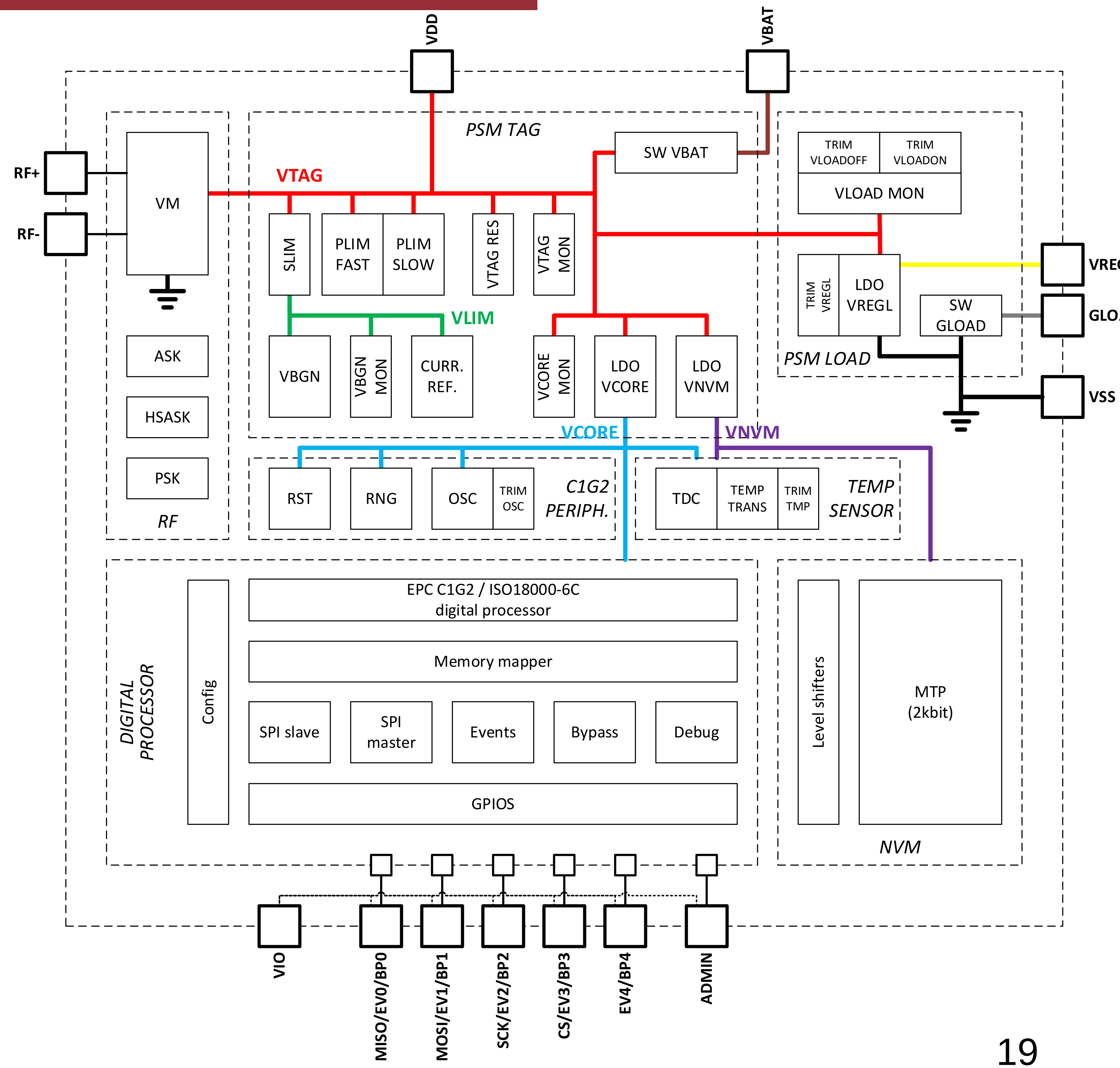




- The communication range is limited by the harvesting capabilities.
- When there is not enough energy available, the system does not consume power.
- When there is a certain amount of energy the system is waked up and operates. It must do the required operation before the energy is finished: energy limited operation.

Power limited vs Energy limited. RFID SENSORS

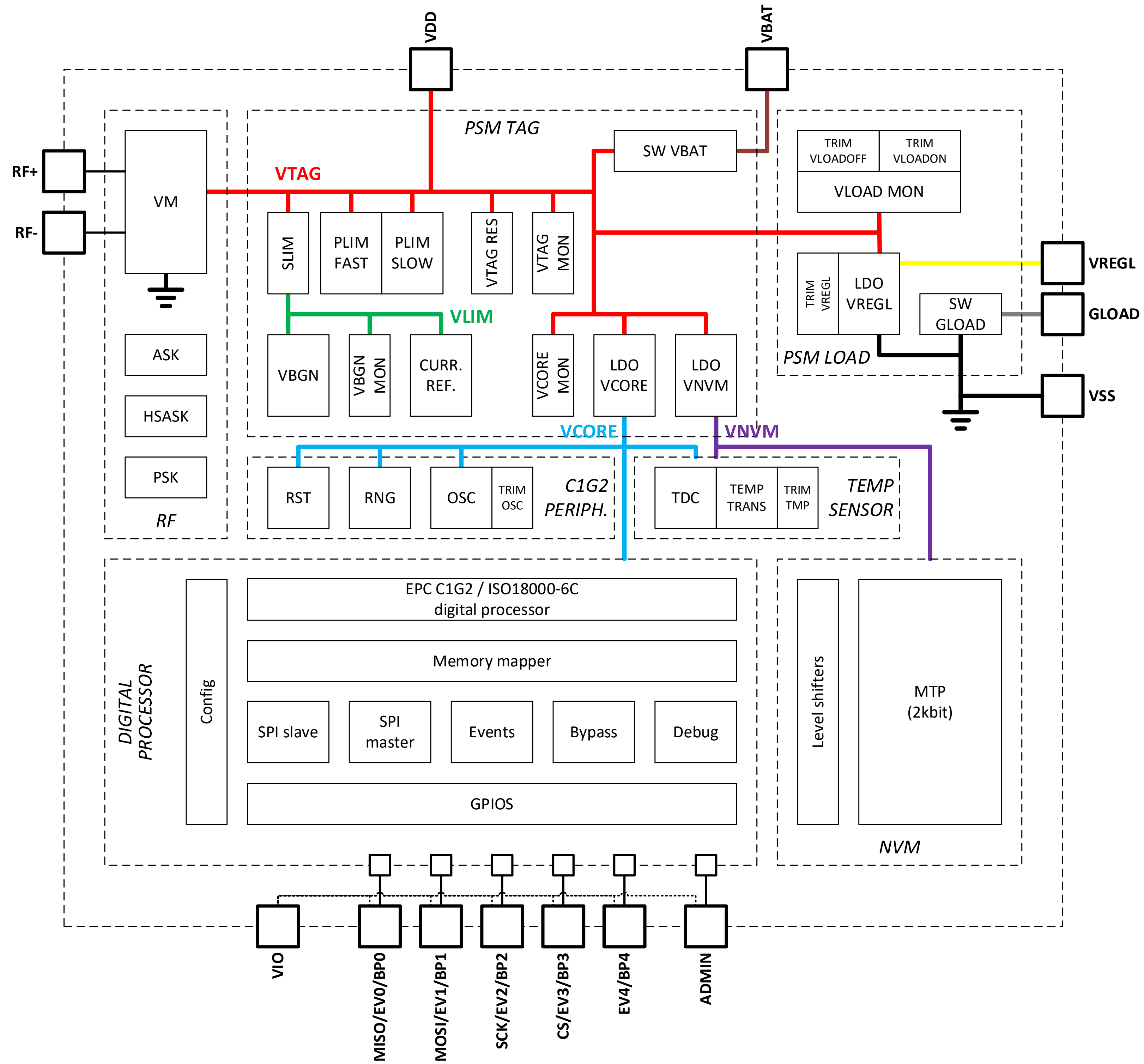
- Everything planned for a smart management of the energy.
- Each block only switched on only when necessary.
- Key element, POR or voltage monitor:
  - Needs to have hysteresis.
  - Switches-on the circuit functional blocks at a reachable voltage value, above the minimum operation voltage.
  - Switches-off at the minimum operation voltage.
  - The energy difference between both states corresponds to the energy required for a single operation.



Power limited vs Energy limited. RFID SENSORS

- Which are the key aspects of RFID sensor?
  - Communication protocols.
  - Power consumption during time=Energy requirement
  - Energy Management system.
  - Harvesters system.

- RFID Identification
  - Von: 1.8V
  - Voff 1V.
  - Csupply: 2nF
  - $\Delta E = \frac{C_{supply}\,(V_{on}^2 - V_{off}^2)}{2} = 2.24nJ$



Power limited vs Energy limited. Summary

- Power limited systems:
  - Require a continuous voltage supply, usually battery assisted.
  - Optimized for minimum average power consumption with duty cycled operation.
  - During sleep mode can:
    - Be ready to receive messages from the network/reader
    - Run a real time clock to perform a duty cycled operation.
    - Do continuous measurements and enable a TX when an event occurs.
  - If harvester assisted, MPPT is critical.
- Energy limited systems:
  - May use a discontinuous energy source with discontinuous supply voltage.
  - Minimum energy/operation: power x time.
  - During sleep mode there is no activity in the load as it is hardly switched-off.
  - The system wakes up when there is enough energy. (time stamp is receiver)
  - If harvester assisted, the MPTT is not critical but the time required to harvest the required energy.

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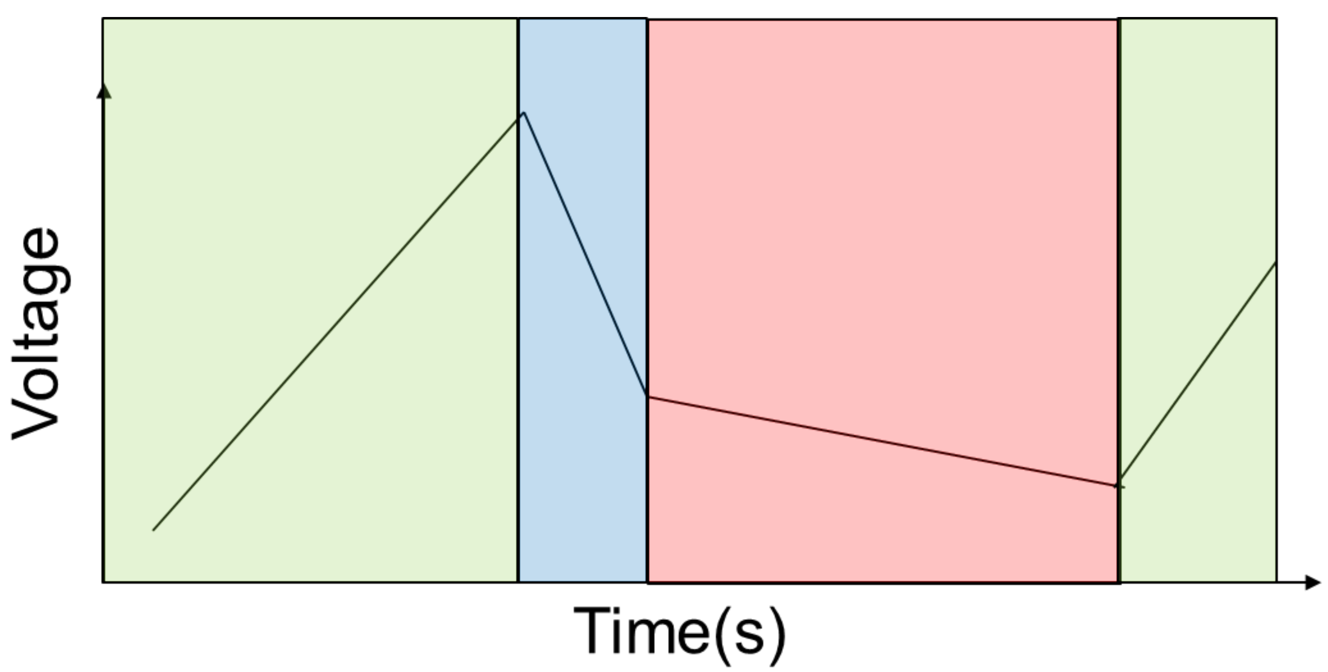
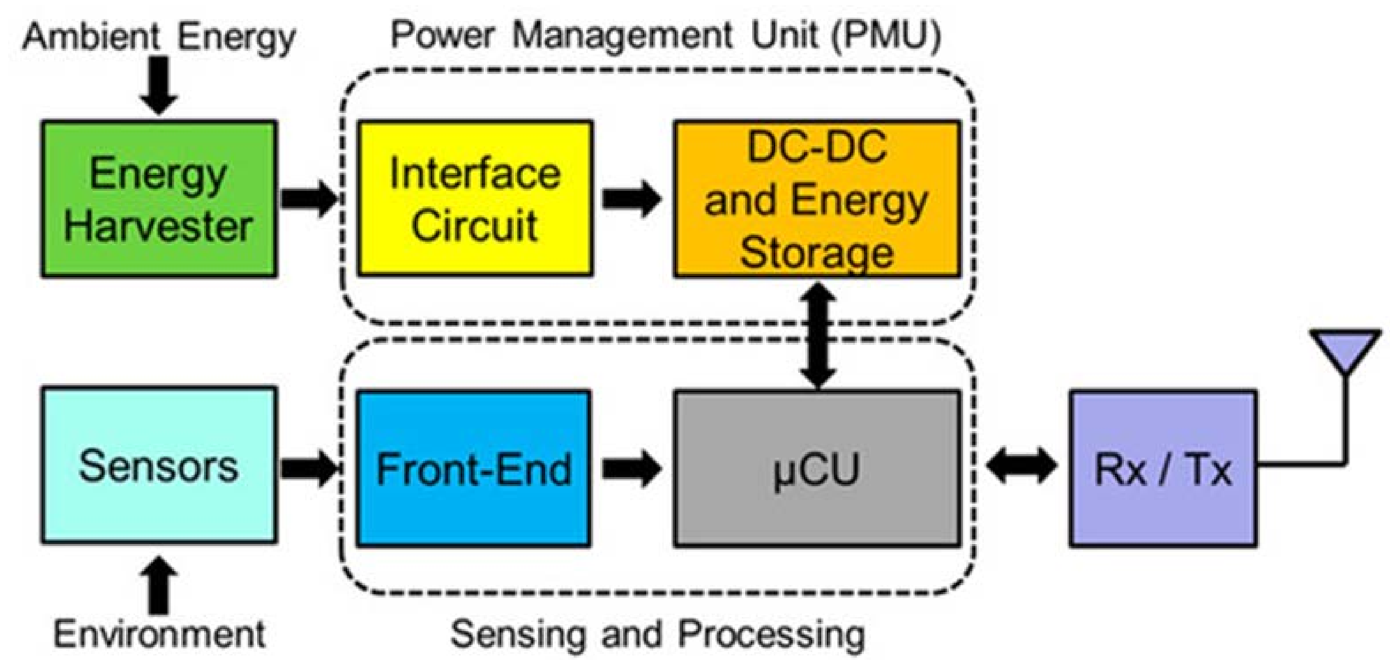
Key aspects of energy limited designs

- Which are the key aspects?
  - Communication protocols
  - Sensors
  - Energy Management system
  - Harvesters system.

Energy budget per measure





Key aspects of energy limited designs

- Which are the key aspects?
  - Communication protocols
  - Sensors
  - Energy Management system.
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Energy budget per measure

- Before taking any decision about your system you need to know your target application.
  - Do I need real time data?
  - Are the communication critical? QoS?
  - Is the measurement time stamp necessary?
  - Does the system require data logging capabilities?
  - Do I need computation in the sensor device?
  - Are Cloud or edge computing an option?

Energy budget per measure

Key aspects of energy limited designs

- Which are the key aspects?
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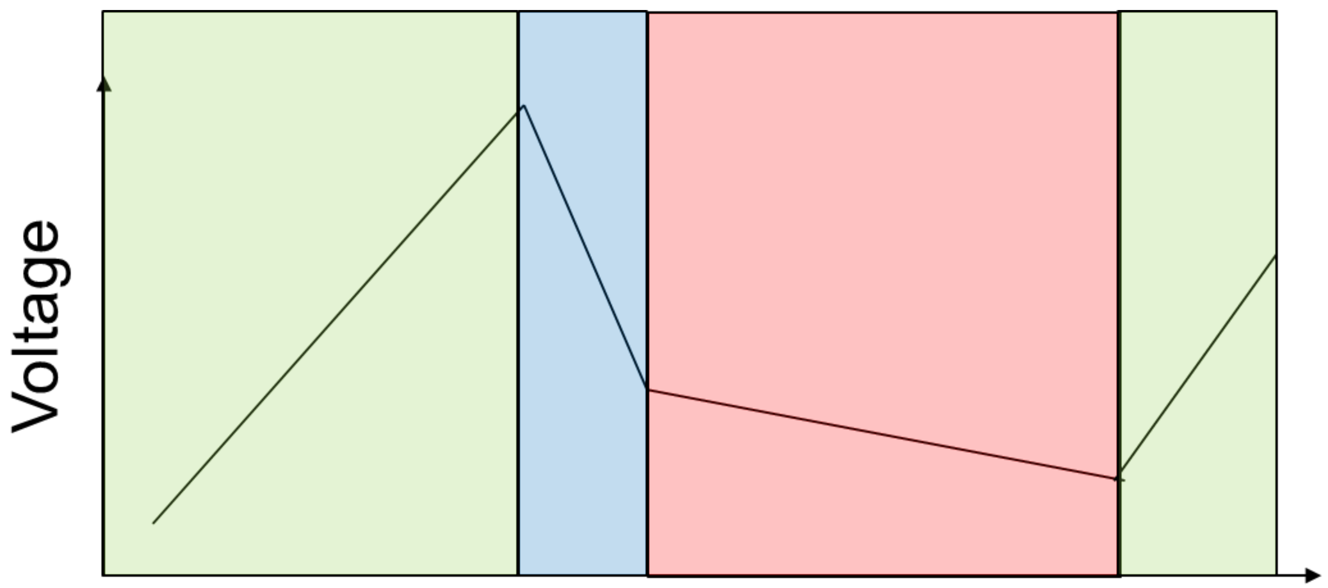
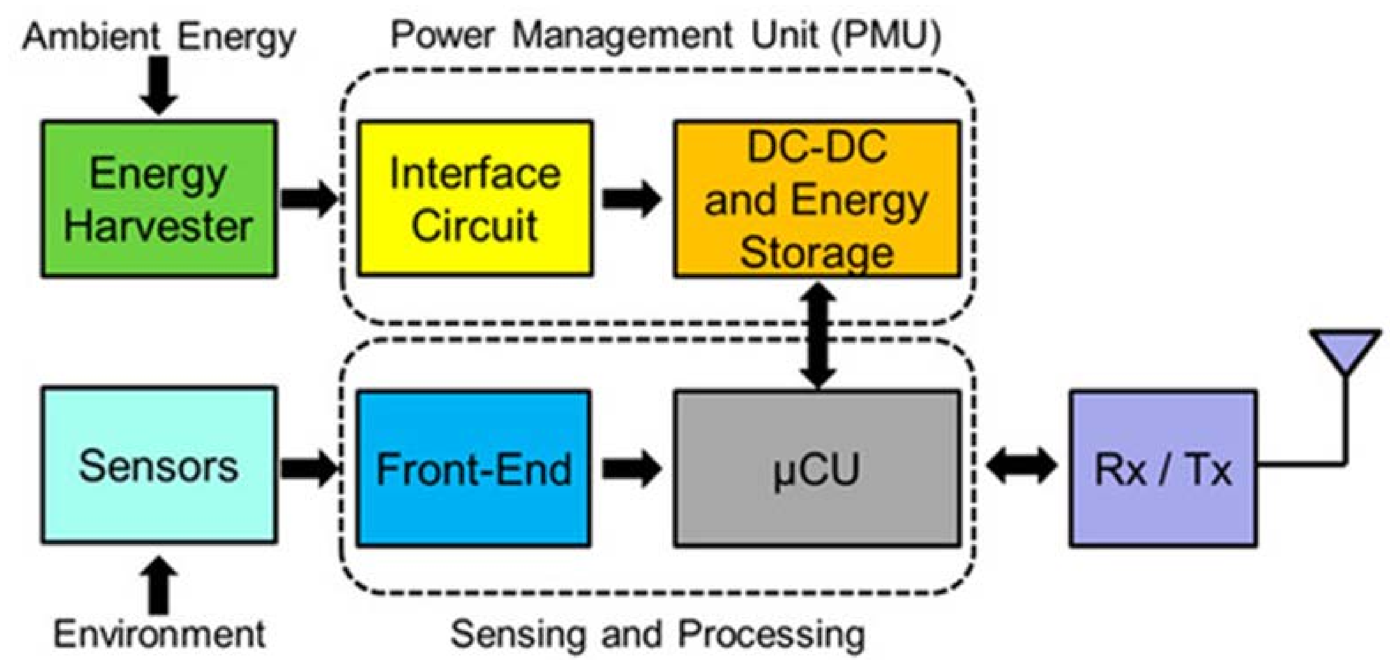
Energy budget per measure

Is our system capable of harvesting enough energy to do a measurement + communication task?





Key aspects of energy limited designs Communication protocol

- **CHARACTERISTICS**
- **Range**.
- Data rate.
- Latency.
- Architecture/Topology
- **QoS.**
- **Mode**
- Cost per device.
- Cost per usage.
- Deployment.
- User experience.

- **PROTOCOL**
- Wired
- **BLE**
- **LORA**
- SIGFOX
- **RFID**
- WIFI
- 5G
- 4G/3G/2G
- NB-IOT
- ZIGBEE
- **CUSTOM PROTOCOLS**

Key aspects of energy limited designs What is Quality of Service (QoS)?

- The QoS helps us defining the level of reliability our communication requires.

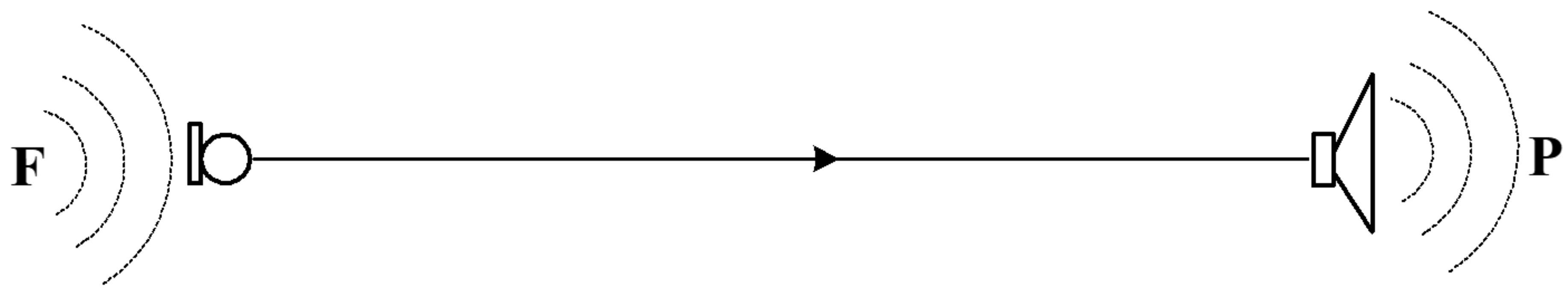
- Taking as reference the 3 levels of QoS defined in the MQTT protocol:

  - *At most once* (0). This level guarantees a best-effort delivery. There is no guarantee of reception. The recipient does not acknowledge receipt of the message. Best if you don't mind if a few messages are lost occasionally.

  - *At least once* (1) Guarantees that a message is delivered at least one time to the receiver. The sender stores and resends the message until it gets and ACK response from the receiver.

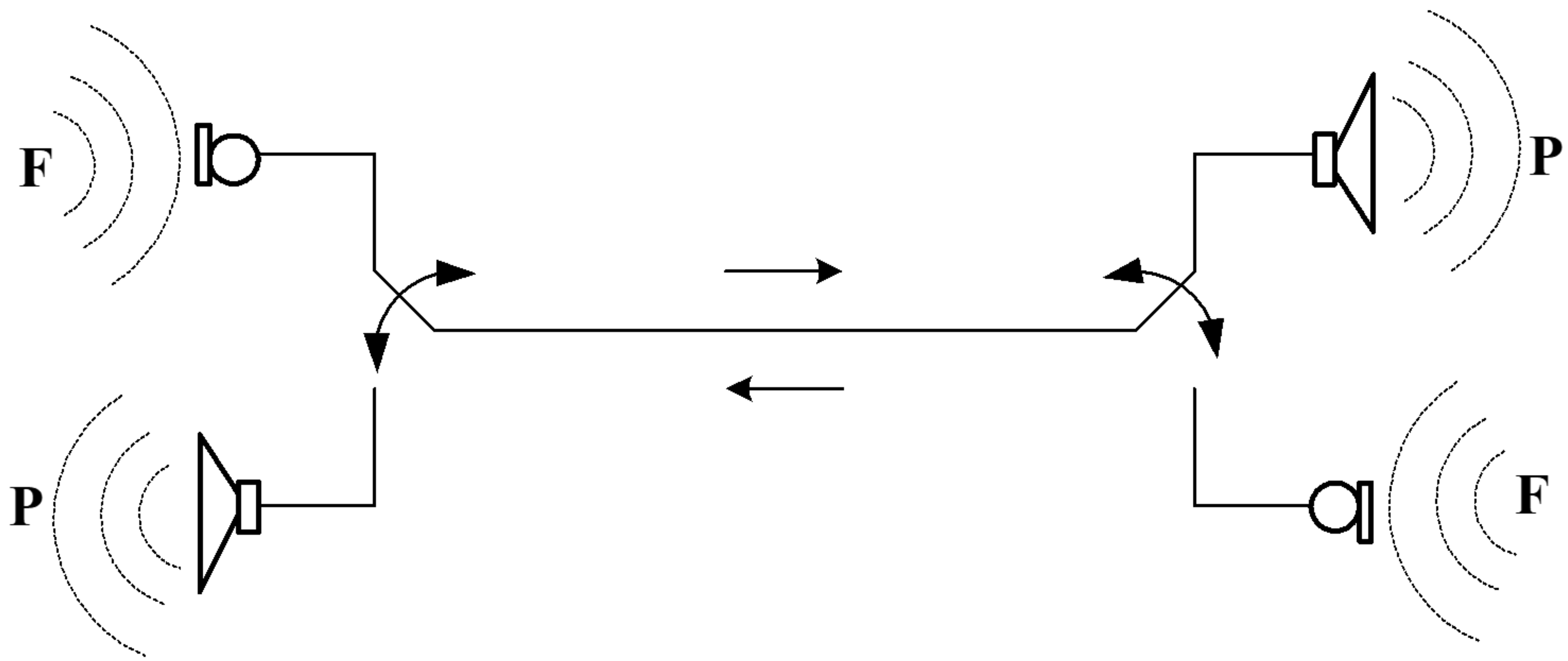
  - *Exactly once* (2) Most complex, requires a 4 step hand-shake between sender an receiver.

Key aspects of energy limited designs
Communication Mode



Simplex (SW)

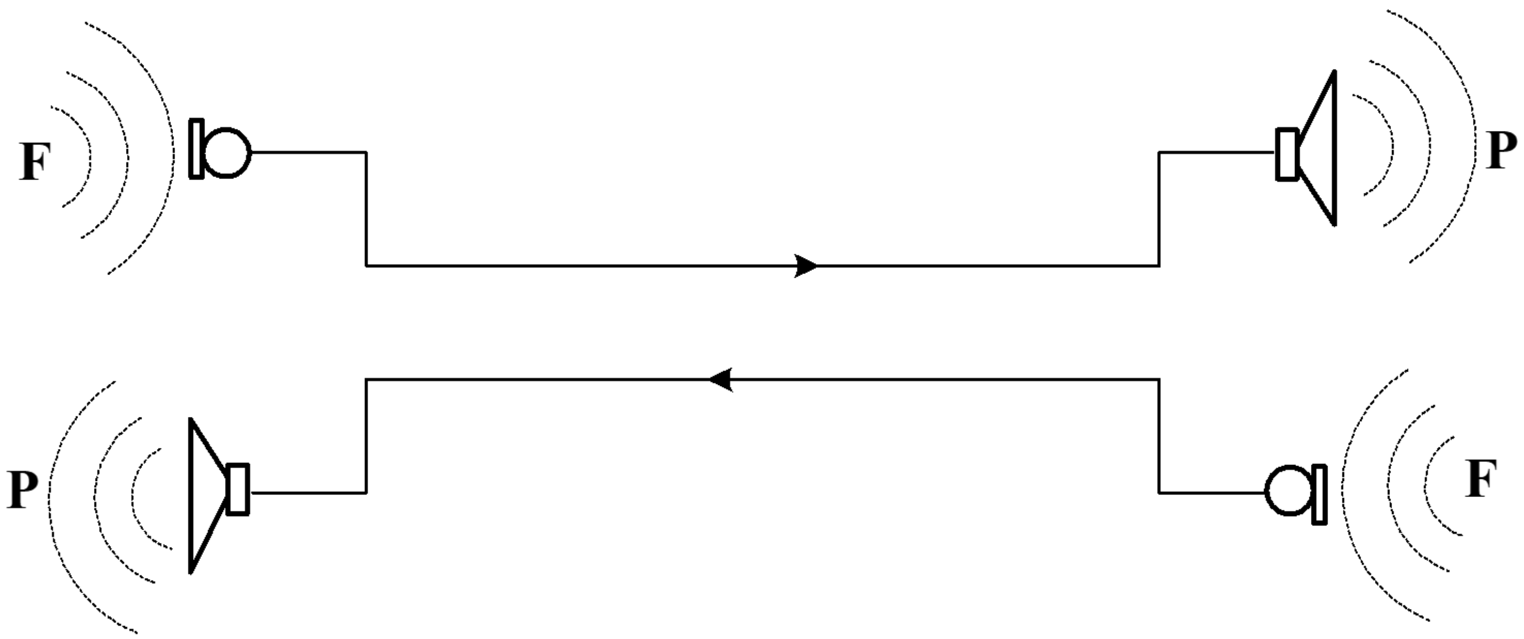
FM radio
(QoS 0)



Half Duplex
(HDX)

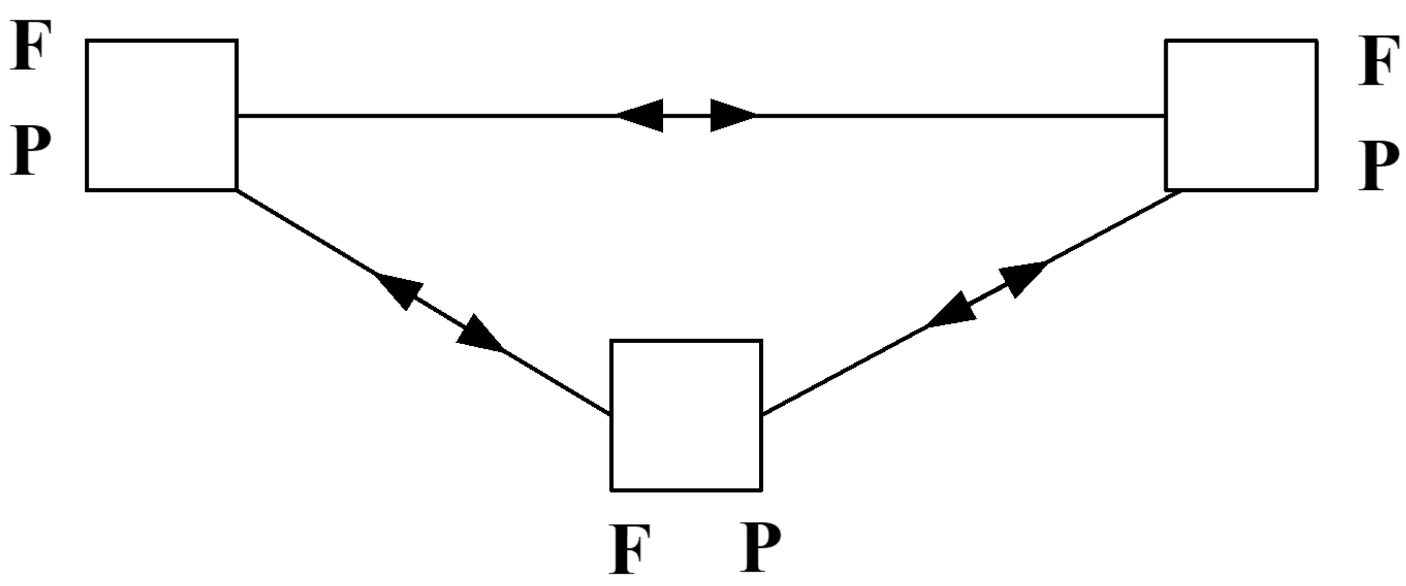
UHF RFID
WALKIE TALKIE

Key aspects of energy limited designs
Communication Mode



Full Duplex
(SW)

Standard celular communication

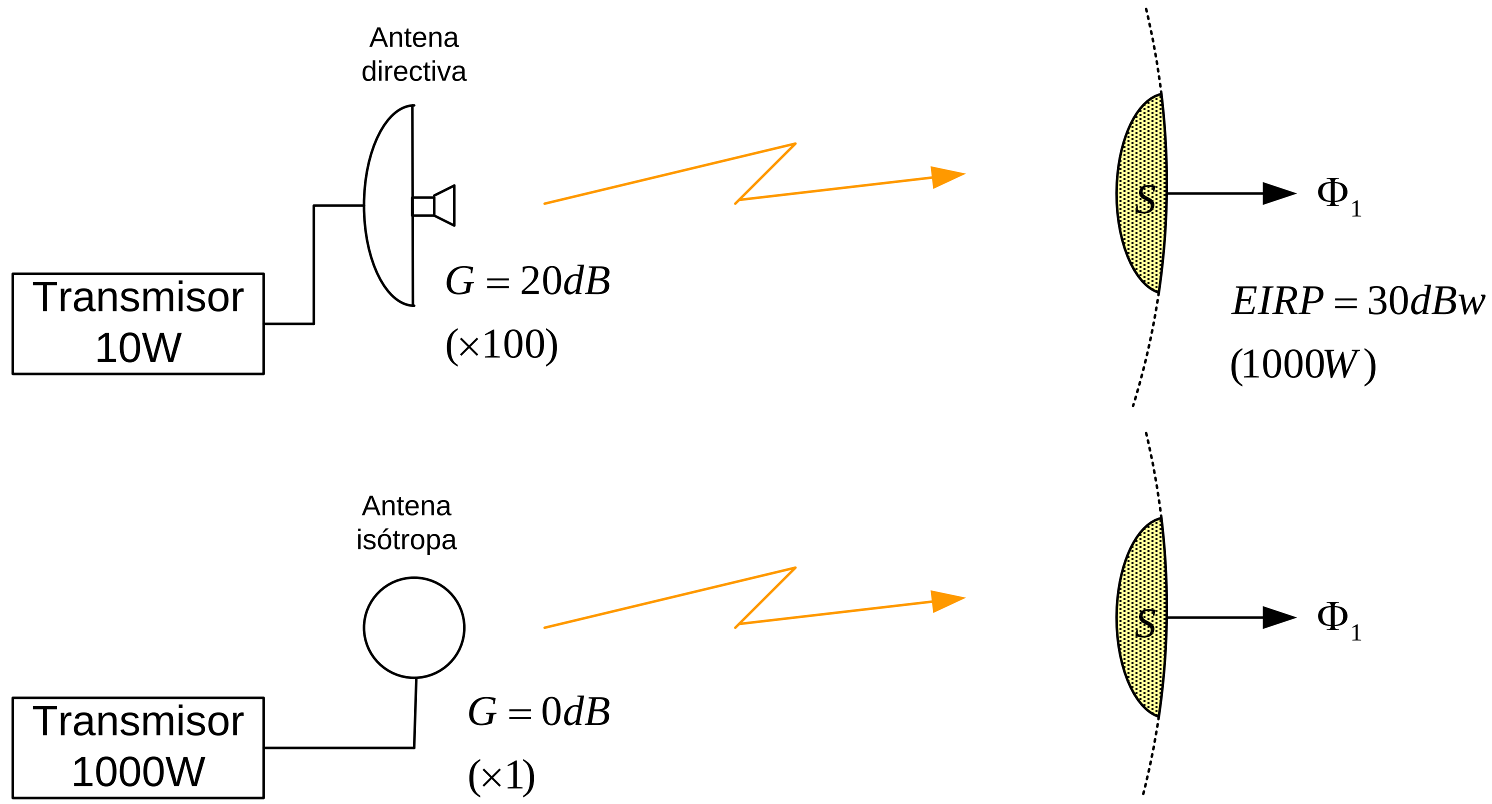


Full/ Full Duplex
(F-FDX)

BLE mesh network

Key aspects of energy limited designs Range

- Maximum distance between sensor and Base station/gateway.
- Limited by several reasons
  - Transmitted power reduces with the square of the distance.
  - Regulation (maximum TX power).
  - Noise/interferences.
- Can be increased:
  - With more power consumption (both in transmitter and receptor).
  - Reducing the data rate.
  - Using specific communication protocols.
  - Using more directive antennas



Key aspects of energy limited designs
Reducing energy budget.

- A way to reduce the power is by matching the range of the radio to the application requirements.

- 0 level QoS is really interesting for energy limited scenarios in order to reduce to the maximum the operation time.

- “Simplex” communication is highly recommended, so after the TX procedure the load is completely switched off. We call this operation mode “Beacon” mode.

- If we want to keep the option of network to sensor node communication:
  - Ultra low-power wake up (around 100nA).
  - RF harvesting, as it is done in RFID sensors.

Key aspects of energy limited designs
Communication protocol

- **CHARACTERISTICS**
- **Range**.
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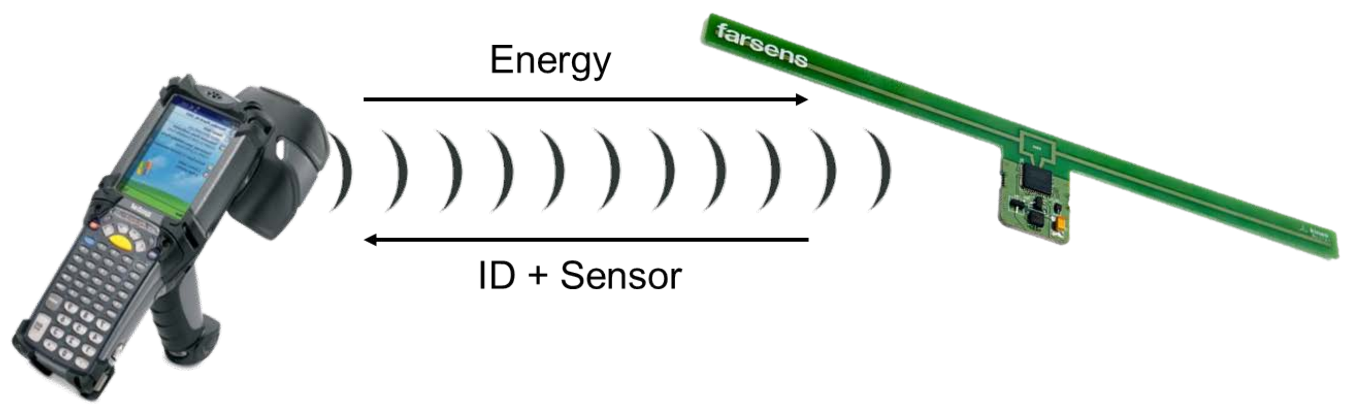
- ZIGBEE
- **CUSTOM PROTOCOLS**

Key aspects of energy limited designs BLE beacon

- From about 10 cm to 10 m, high transmission rate up to 1 Mbit/s
- Most common protocol. Instantaneous deployment with mobile phones that can act as gateways.
- Support point-to-point, broadcast (beacon), mesh, and other modes of communications.
- Very low power. In beacon mode (simplex, level 0 QoS) (3 submission/cycle), **70uF capacitor loaded with 3.3V is enough!**

Key aspects of energy limited designs RFID

- Bidirectional communication. (Not common in energy based systems). 4-5 meters of range with sensor. 15 meters without sensor.



- In these systems, with only RF harvesting, the communication range in currently limited by that aspect. Surprisingly, it is a (Half-duplex with level 2 QoS)-> expensive readers.

- **2nF with 1.8V for ID, neglectable in comparison with sensor requirements.**

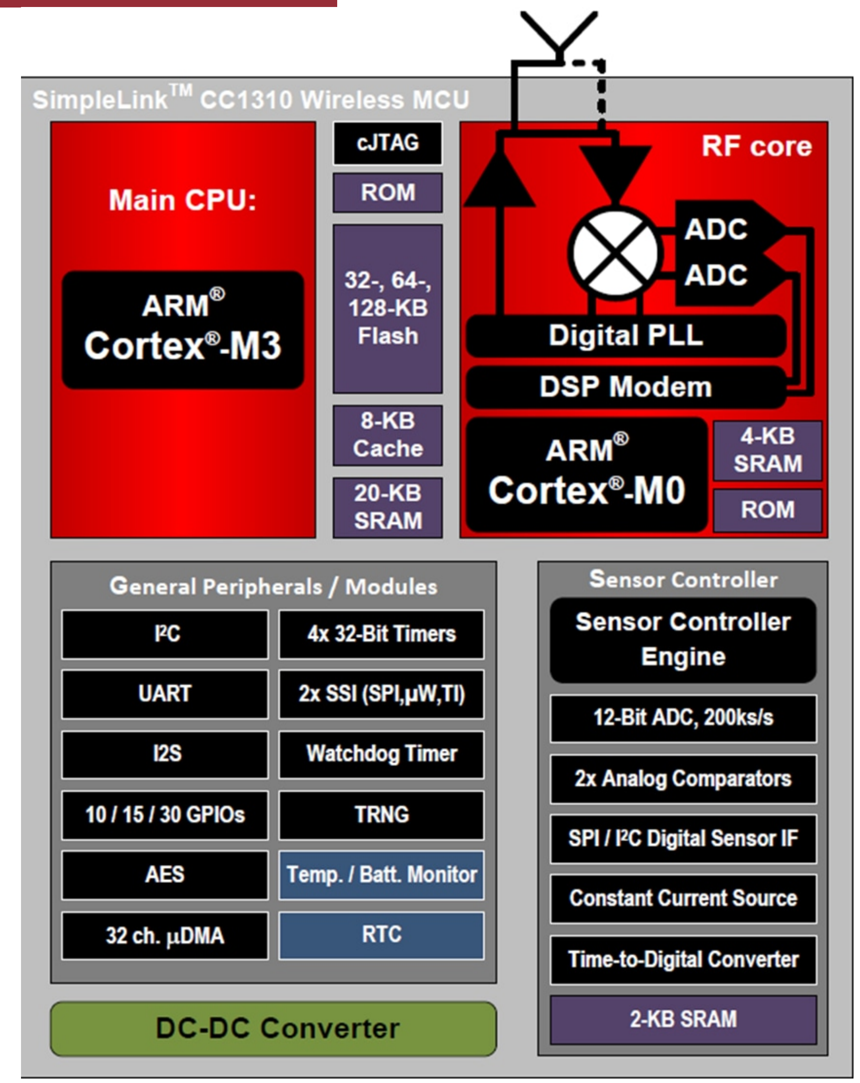
Key aspects of energy limited designs
Long range communications

- Those based on mobile network discarded. (Pay per Use)
- Low power wireless access: Specific networks at sub-1GHz frequency for WSN and IoT.
  - LORAWAN
  - SIG-FOX
  - NB-IOT
  - MIOTY
  - Custom protocol.

- Lora very good for power limited, not good for energy (low power but long time).
- Custom protocol selected for evaluation purposes

Key aspects of energy limited designs
Custom communication protocol

- A custom communication protocol would allow us to reduce the energy consumption of the communication to the minimum required by the application.
- CC1310 communication module is a very easy to use low power platform where is possible to evaluate different communication protocols.
- Uses sub-1GHz free bands.



Key aspects of energy limited designs Custom communication protocol

- Different protocols have been implemented in TX and RX and the TX board has been supplied by a capacitor, trying to find the required minimum
- **If it is possible to load a 70uF cap with 3.3V, long communication range reachable> theoretically 400m.**
- Non-intuitive idea: best from an energy point of view higher data rates -> higher power consumption but smaller time.

Communication protocol	Rate [kps]	Expected Distance [m]	Csupply	Minimum voltage
50kps/GFSK/w CRC	50	784	150uF	3.3V
500kps/GFSK w CRC	500	400	68uF	3.3V
OOK 4.8 KPS	4.8	1083	500uF	3.3

Key aspects of energy limited designs Communication summary

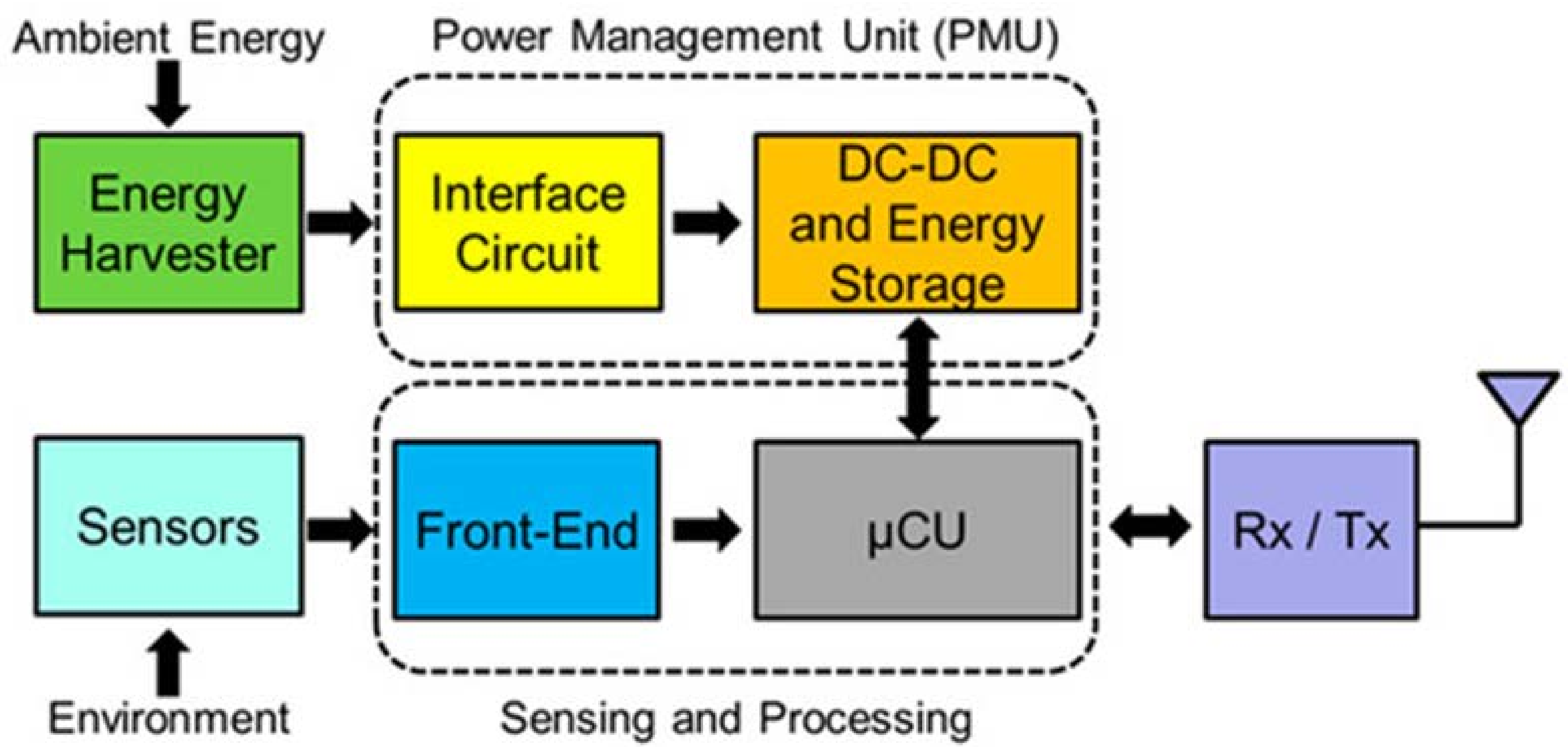
- Beacon mode preferred (QoS 0, simplex)
- Short range:
  - RFID: up to 5 meters, 2nF with 3.3V. Integrated RF harvester. Expensive reader.
  - BLE: up to 10 meters, 70uF with 3.3V. Very popular reader.
- Long Range:
  - Better high data rate than low->shortest TX time->smallest energy.
  - LORA: Discarded because slow operation.
  - Custom protocol sub 1GHz, : up to 400m, 70uF with 3.3V

- **If we load 70uF with 3.3V we can communicate in both long-range and short-range with commercially available solutions**

Key aspects of energy limited designs
Sensors

- Which are the key aspects?
  - Communication protocols
  - **Sensors**
  - Energy Management system.
  - Harvesters system.

Energy budget per measure



Key aspects of energy limited designs
Sensor

- All the sensor that requires heat to operate are discarded. (or hybrid solution required)
- If you need degasification using heat, it can be done with direct RF (10mA-30mA depending on the protocol) or hybridsolution
- Must be low power and handle irregular voltage supplies, below the operation region, without current peaks.
- Should have a pulsed operation option.

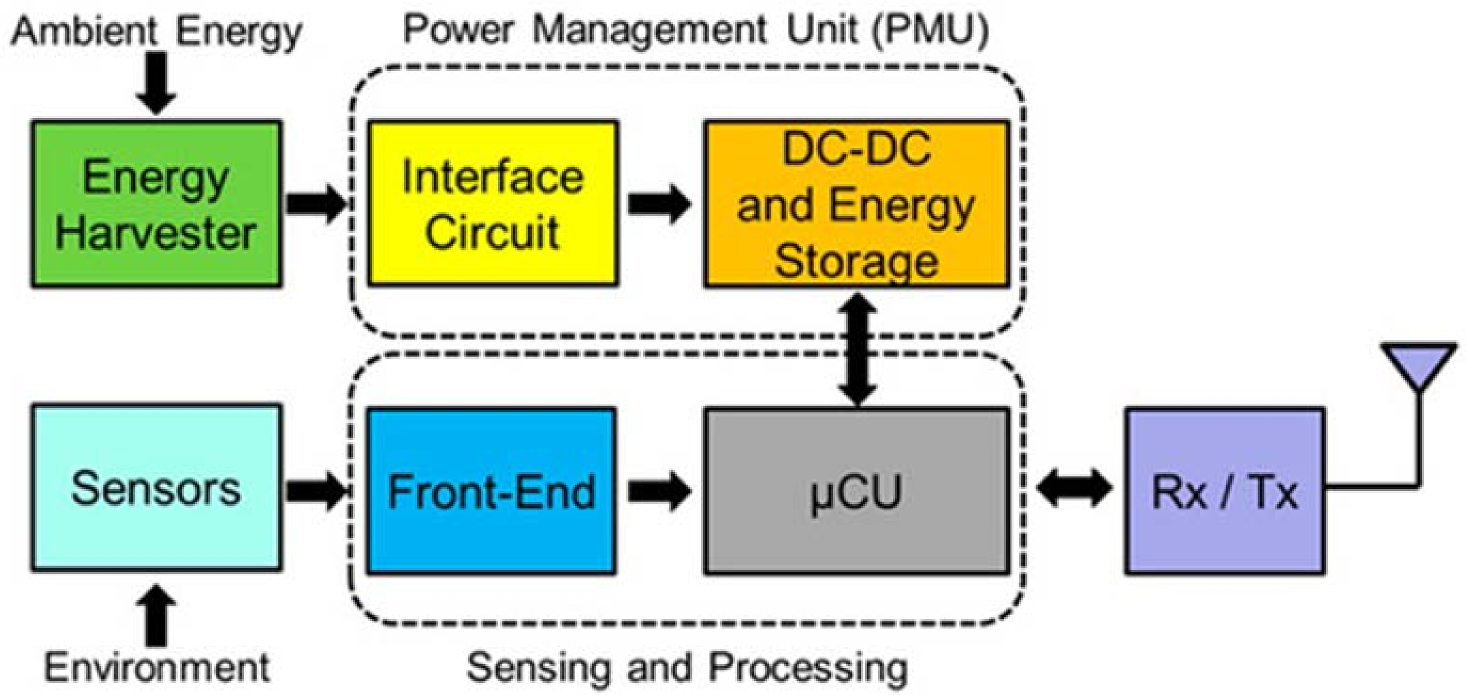
If not, the PMU may handle this.

- In analog output will need to include a signal conditioning and ADC module).

Key aspects of energy limited designs Sensor

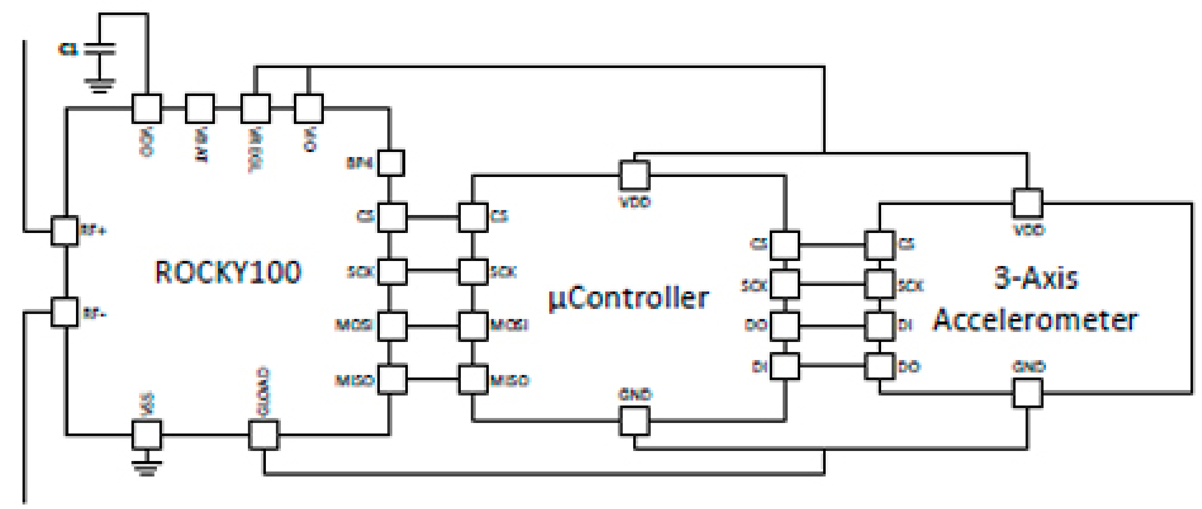
- May require a microcontroller to be able to communicate with the communication module (depends on the programmability of this last). This allows very flexible energy management implementation on the microcontroller.

- Can implement ML algorithms using Tensor Flow Lite in the microcontroller.

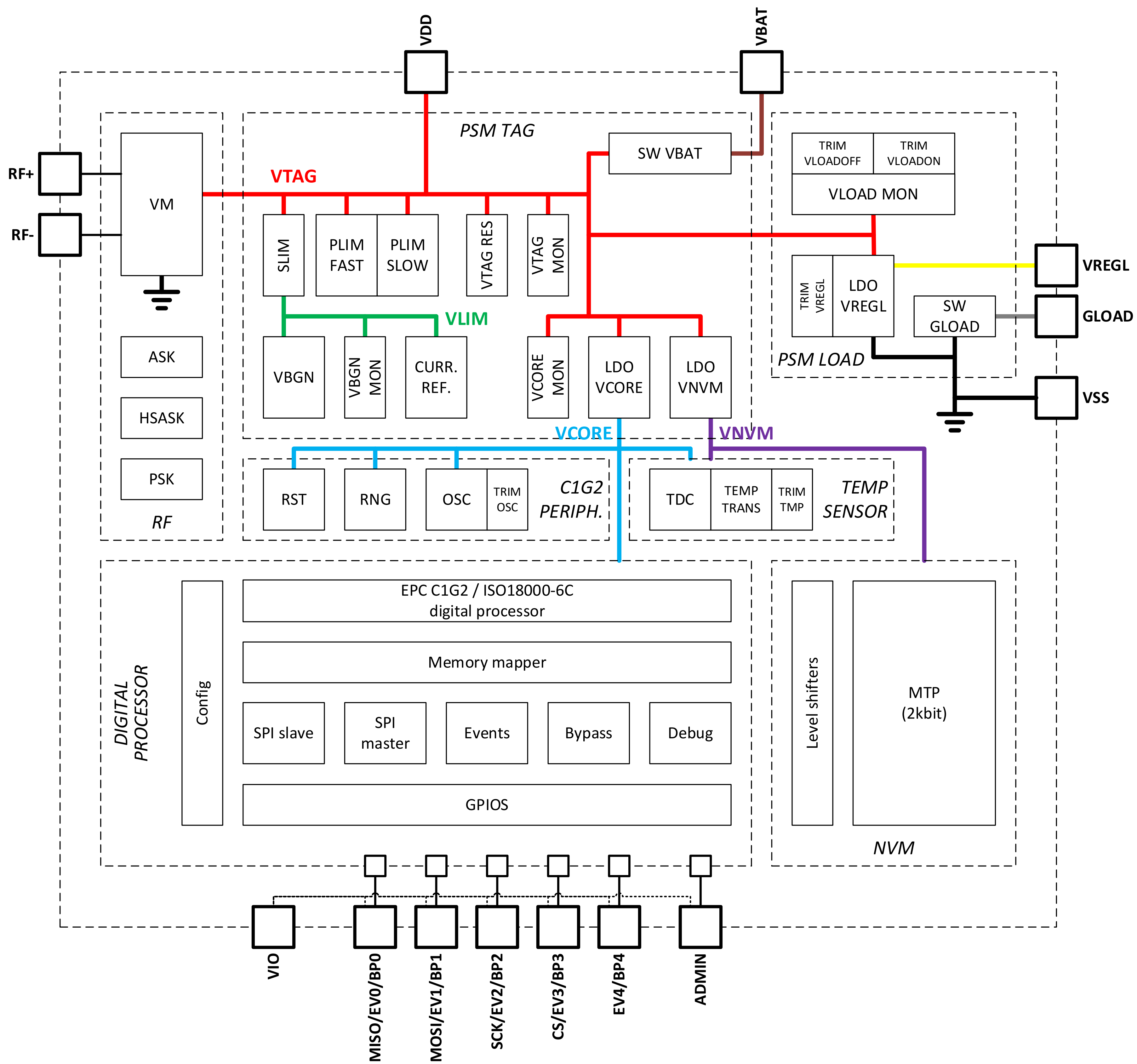


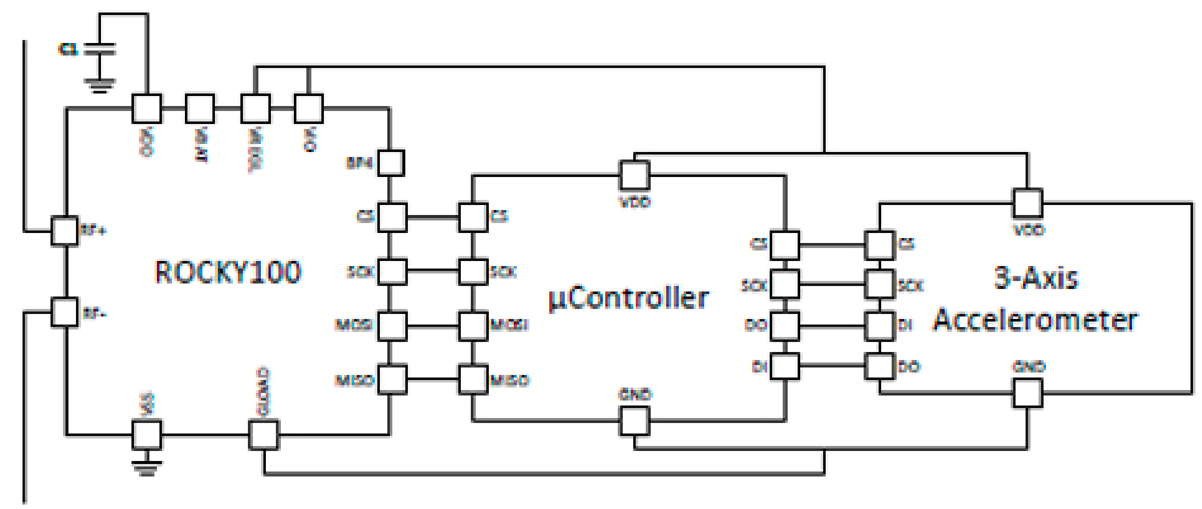
Key aspects of energy limited designs RFID sensor example

- UHF RFID chip compatible with EPC GEN 2 RFID reader.
- Designed and implemented in TSMC180nm technology by Tecnun and Farsens.
- Not programmable, but configurable. (no flash memory but EEPROM)
- Configurable output voltage (VREGL) & monitor.
- Two hard switches to cut the power from the LOADs
- SPI interface that may be controlled by standard RFID commands.
- Microcontroller to interface between commercial sensor and the chip.



Key aspects of energy limited designs
RFID sensor example





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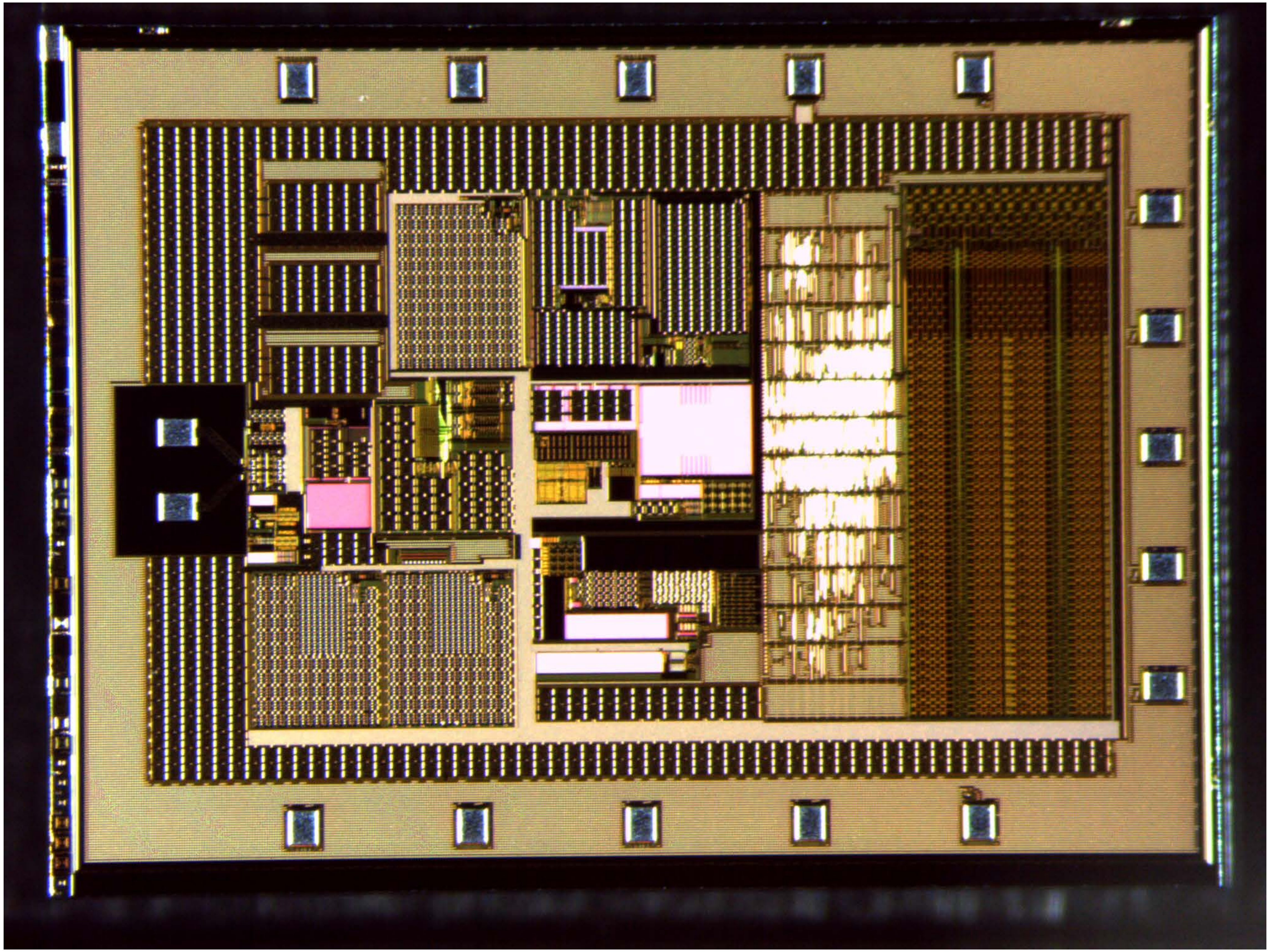
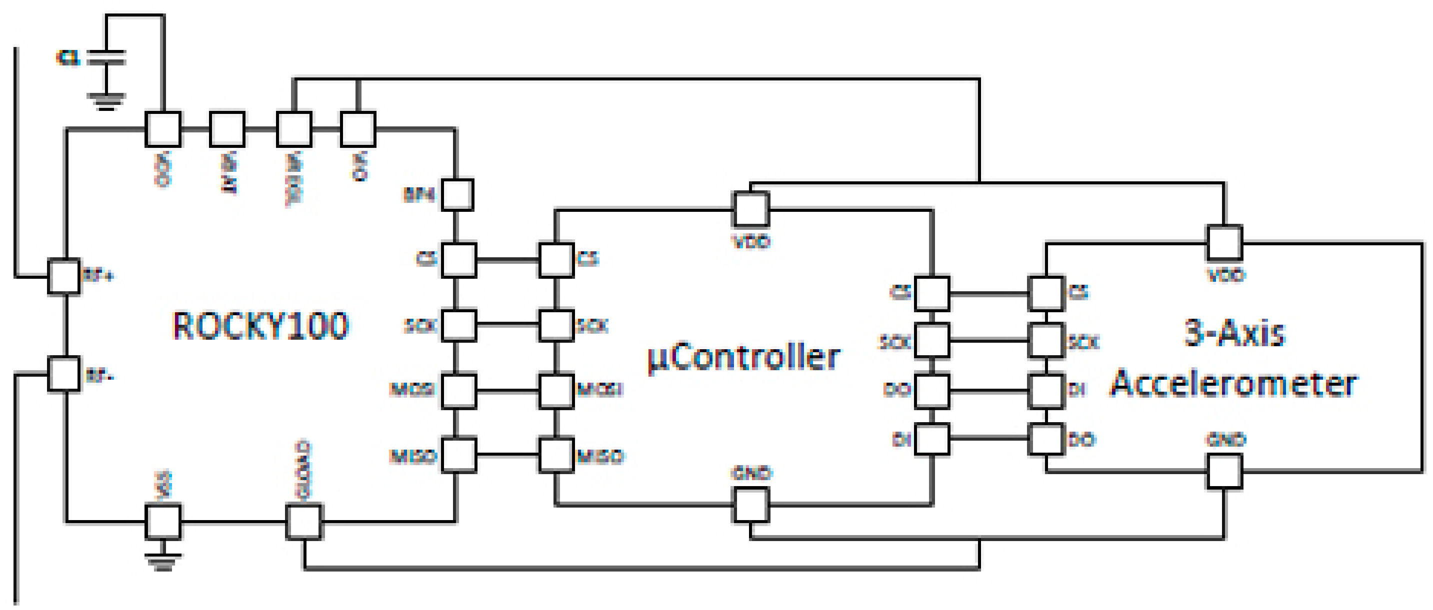


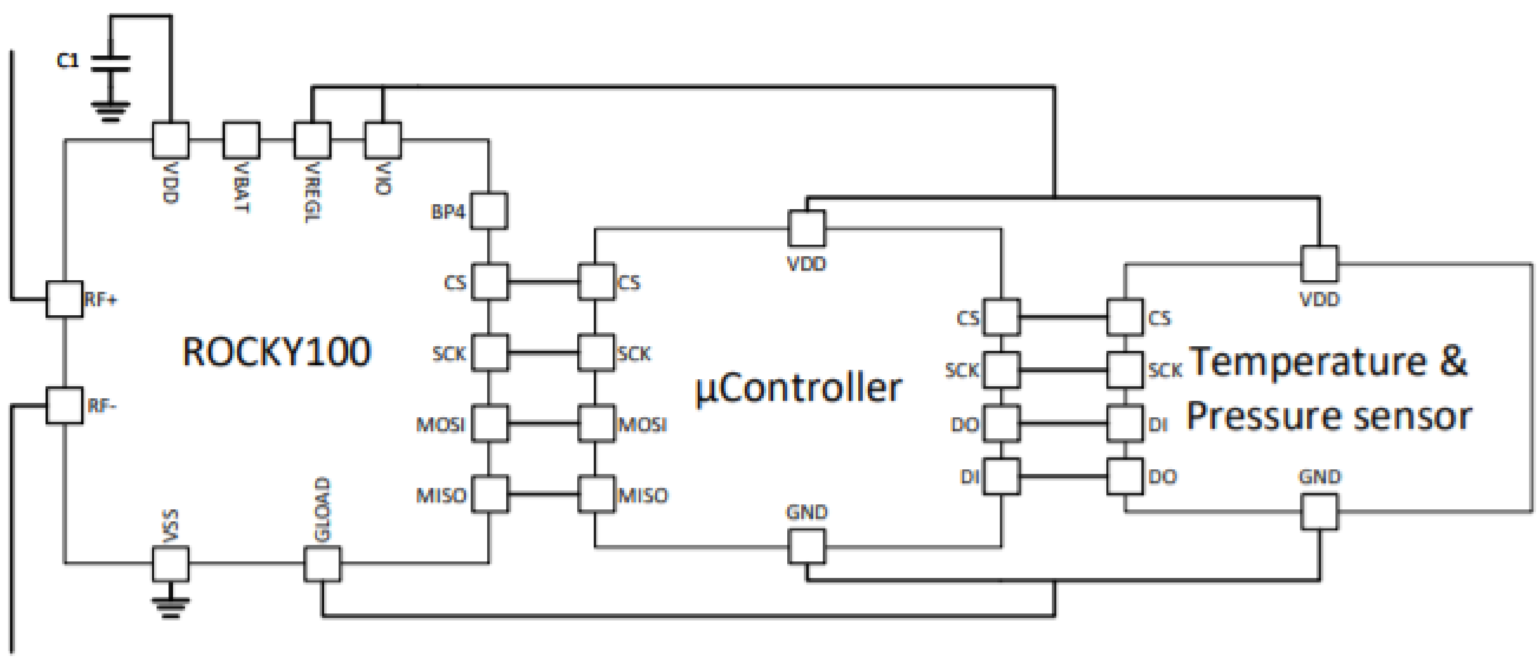
Key aspects of energy limited designs
RFID acceleration sensor



- 3-axis accelerometer (X,Y,Z)
  - Acceleration range: ±4g
  - Acceleration accuracy: ±40 mg
  - Acceleration resolution: 2mg

- Communication independent from external capacitor (C1).
- Acelerator:LIS3DH
- C1 for correct measuring: 22uF with 3.3V

Key aspects of energy limited designs RFID temperatura&pressure sensor



- **Ambient Temperature sensor**
  - **Range: -30°C to 85°C**
  - **Accuracy: ± 2°C**
- **Barometric Pressure sensor**
  - **Range: 260 hPa to 1260 hPa**
  - **Accuracy: ± 0.2 hPa**

- Sensor: LPS25HB
- C1 for correct measuring: 44uF with 3.3V

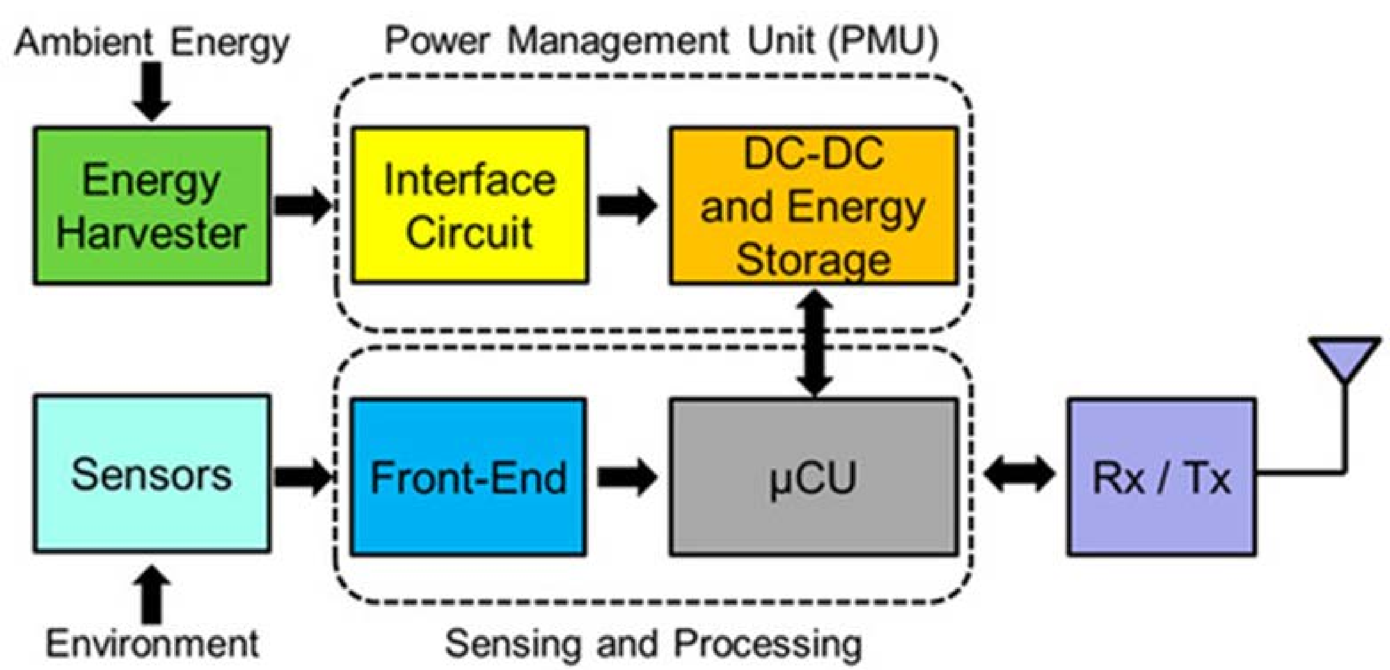
Key aspects of energy limited designs
Sensor and microcontroller summary

- Many sensors can be done wireless with this chips, as far as the sensor power consumption is low and can switch-on and off.
- The microcontroller may be interesting to give flexibility to the system. However SoC such as the CC1310 previously discussed already integrate a microcontroller.
- Regarding the power budget.
  - 22uF would be enough for accelerometers.
  - 44uF would be enough for temperature & pressure sensors.
- **If we are able to load 3,3V into a 44uF capacitor we ensure a great amount of possible sensors to read!!**

Key aspects of energy limited designs

- Which are the key aspects?
  - Communication protocols
  - Sensors
  - **Energy Management system.**
  - **Harvesters system.**

Energy budget per measure



As far as we can load 110uF with 3.3V we will be able to transmit temperature/pressure/acceleration/resistance measurements using BLE (10 m away) or a custom sub 1GHz protocol with up to 400m of range.

Can we?

- Is it possible to load a 110uF capacitor with 3.3V using an environmental harvester? Depends on:
  - The energy generator and its excitation.
  - The correct power management strategy.
  - The resistive load that the voltage monitor represents.
  - The time that we have for doing so. Is it critical?

Key aspects of energy limited designs
Energy generator and its excitation

- Power density and outputs

Energy Source	Power Density
Solar (outdoors sunny day)	15 mW/cm^2
Solar (indoors)	10 $\mu W/cm^2$
Vibration (human motion ~Hz)	4 $\mu W/cm^3$
Vibration (machines ~KHz)	800 $\mu W/cm^3$
Radiant RF (GSM)	0.1 $\mu W/cm^2$
Radiant RF (WiFi)	0.01 $\mu W/cm^2$
Push buttons	50 $\mu J/N$
Thermoelectric (human body)	40 $\mu W/cm^2$

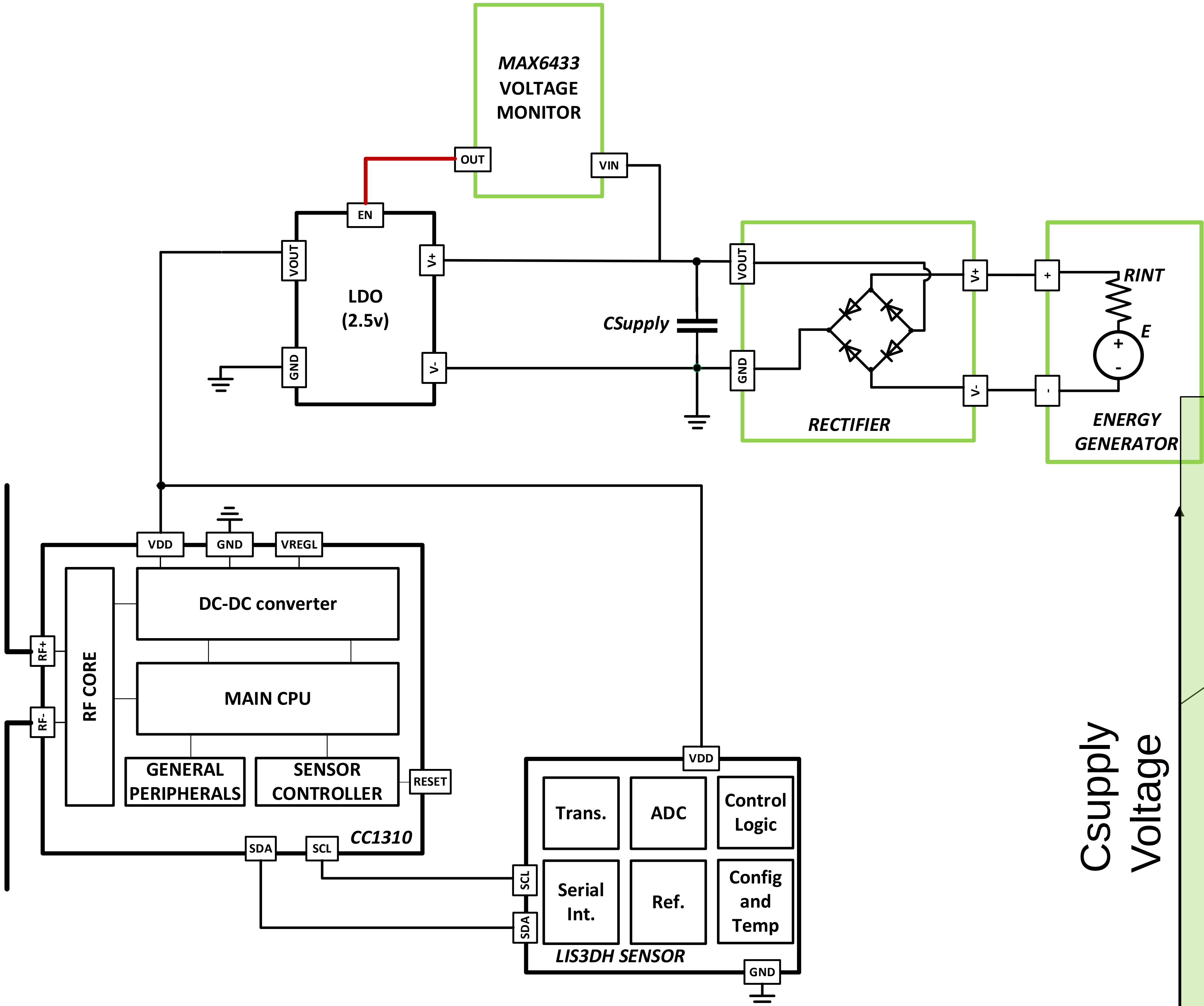
Energy Source	Input Voltage (V)
Thermoelectric (TEG)	50 mV - 300 mV
Indoor photodiode	200 mV - 300 mV
Outdoor photodiode	300 mV - 450 mV
Indoor solar cell	500 mV - 800 mV
Outdoor solar cell	1.2V - 1.9V
Piezoelectric impact	AC attenuated pulse w/ peak @5-20V, 3 - 5 cycles and frequency 50 - 200Hz
Piezoelectric vibration	AC 1-3V
Triboelectric sliding	AC 600V - 1000V

- Very dependent on the application:
  - SENSOFT Project-> Makes no sense harvesters based on movement.
  - iHearth Project-> Triboelectric nanogenerator may be useful.

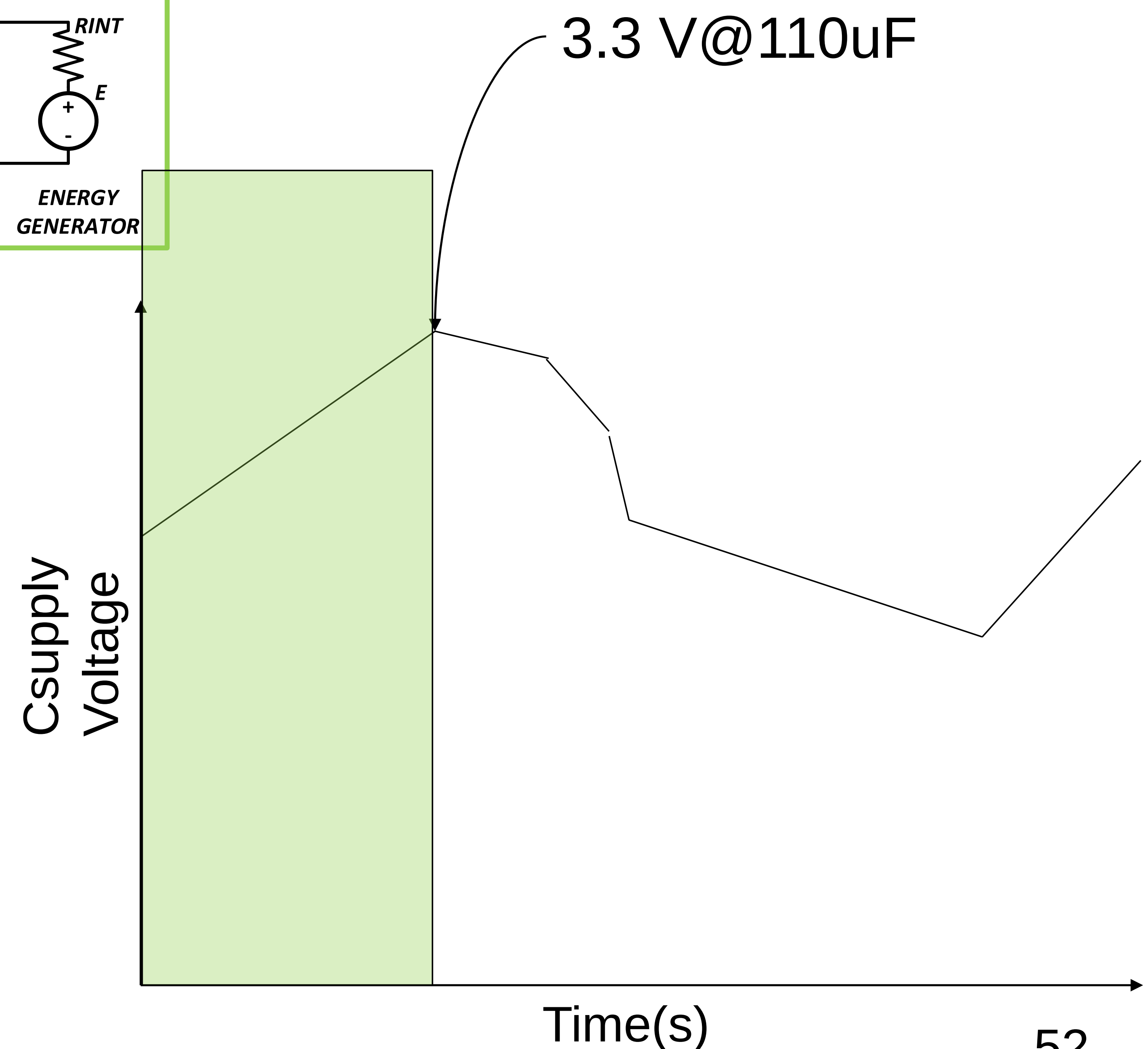
Key aspects of energy limited designs Energy management and harvesters

- Is it possible to load a 110uF capacitor with 3.3V using an environmental harvester? Depends on:
  - The energy generator and its excitation. -> **I am just the electronic guy ☺**
  - The correct power management strategy.
  - The resistive load that the voltage monitor represents.
  - The time that we have for doing so. Is it critical?

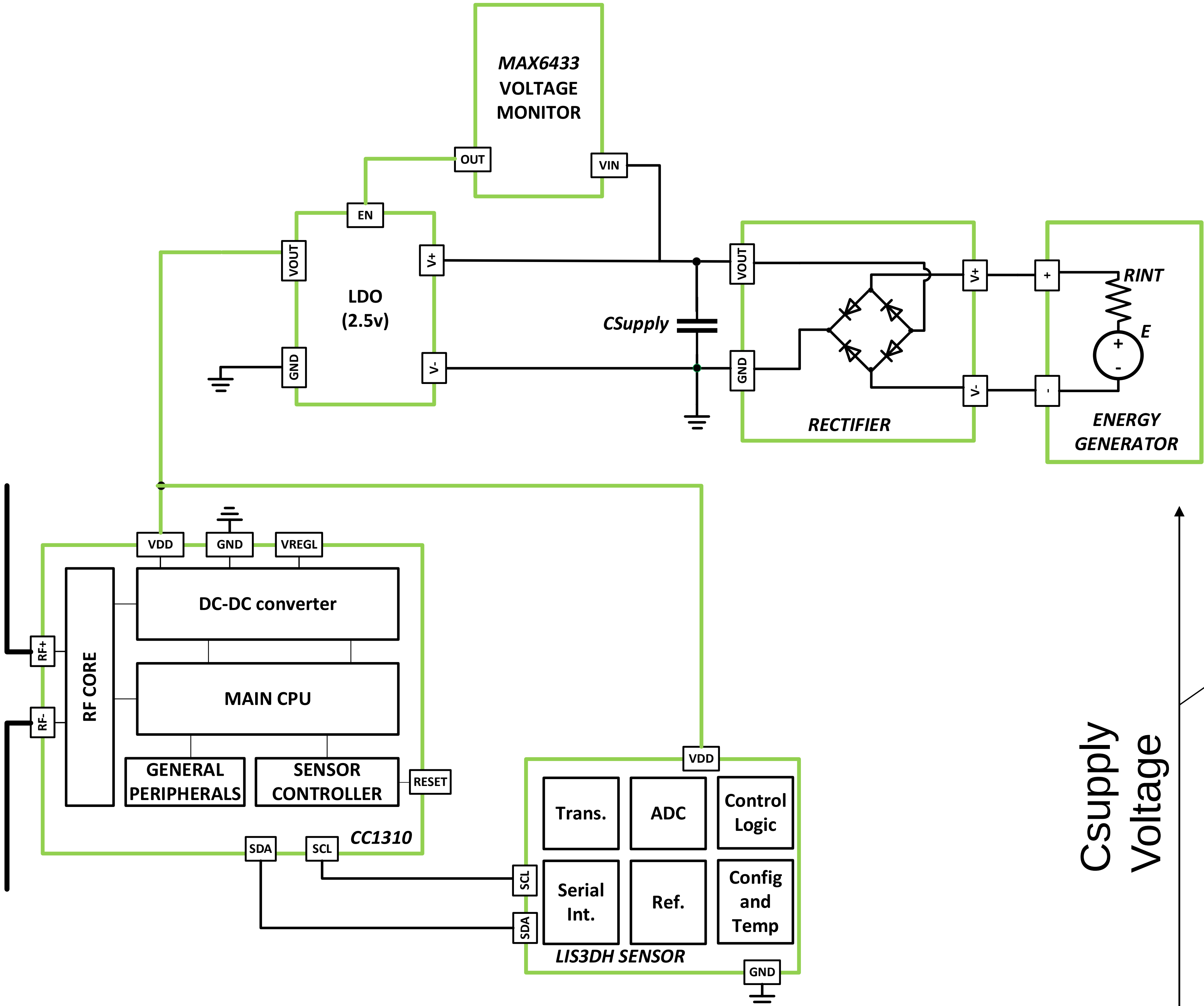
Key aspects of energy limited designs
Power management strategy



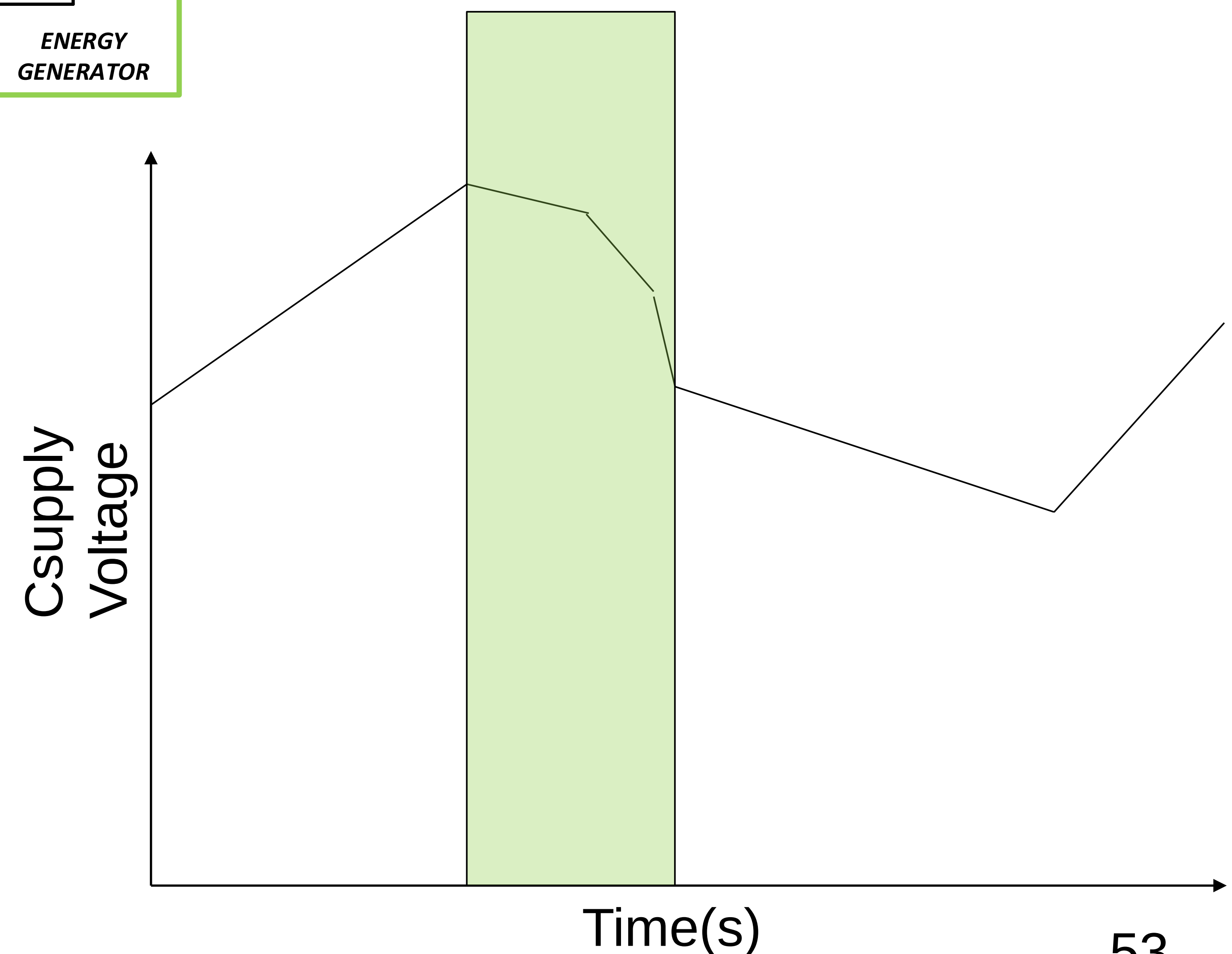
- The harvesting element charges the supply capacitor until the desired energy is obtained.



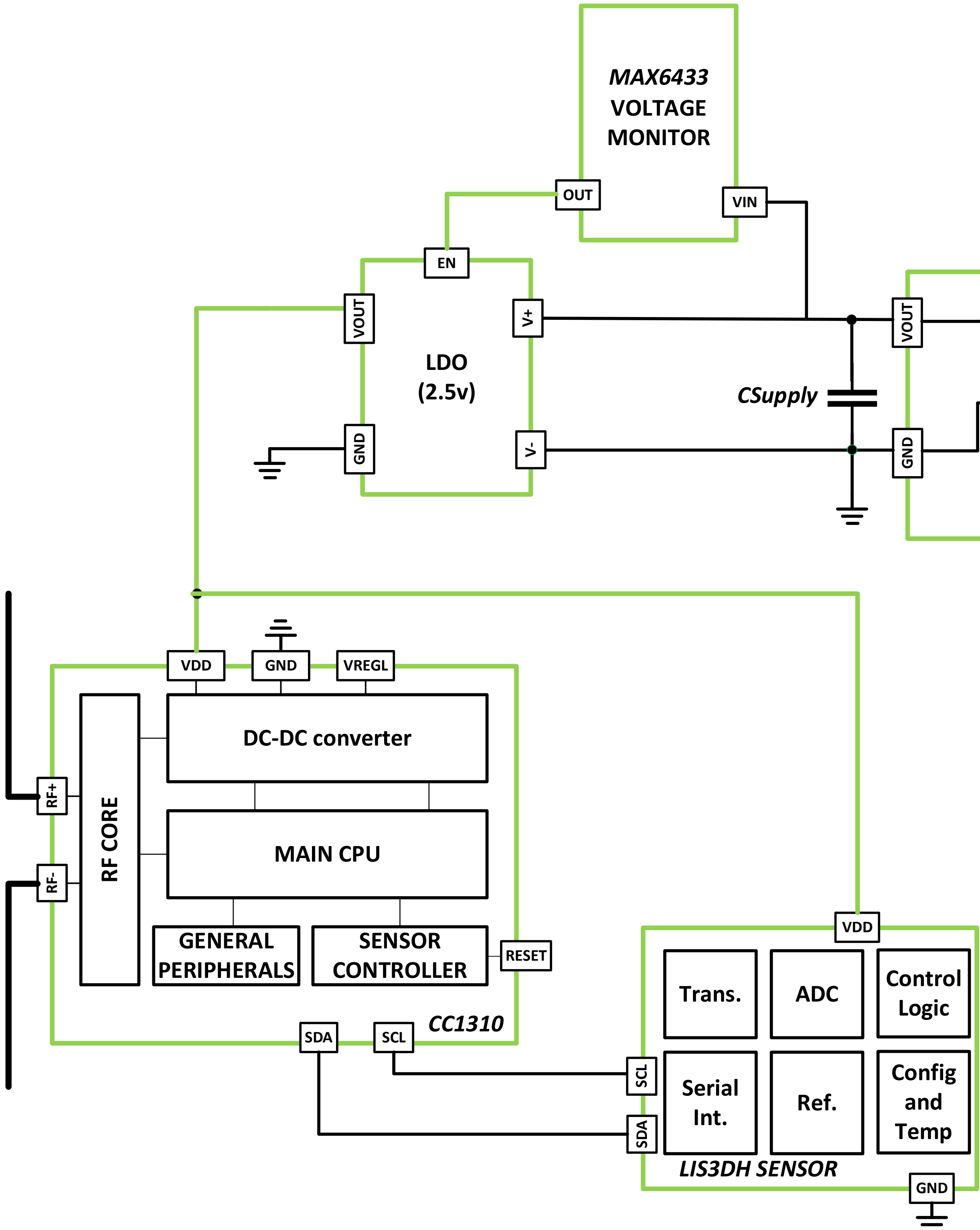
Key aspects of energy limited designs
Power management strategy



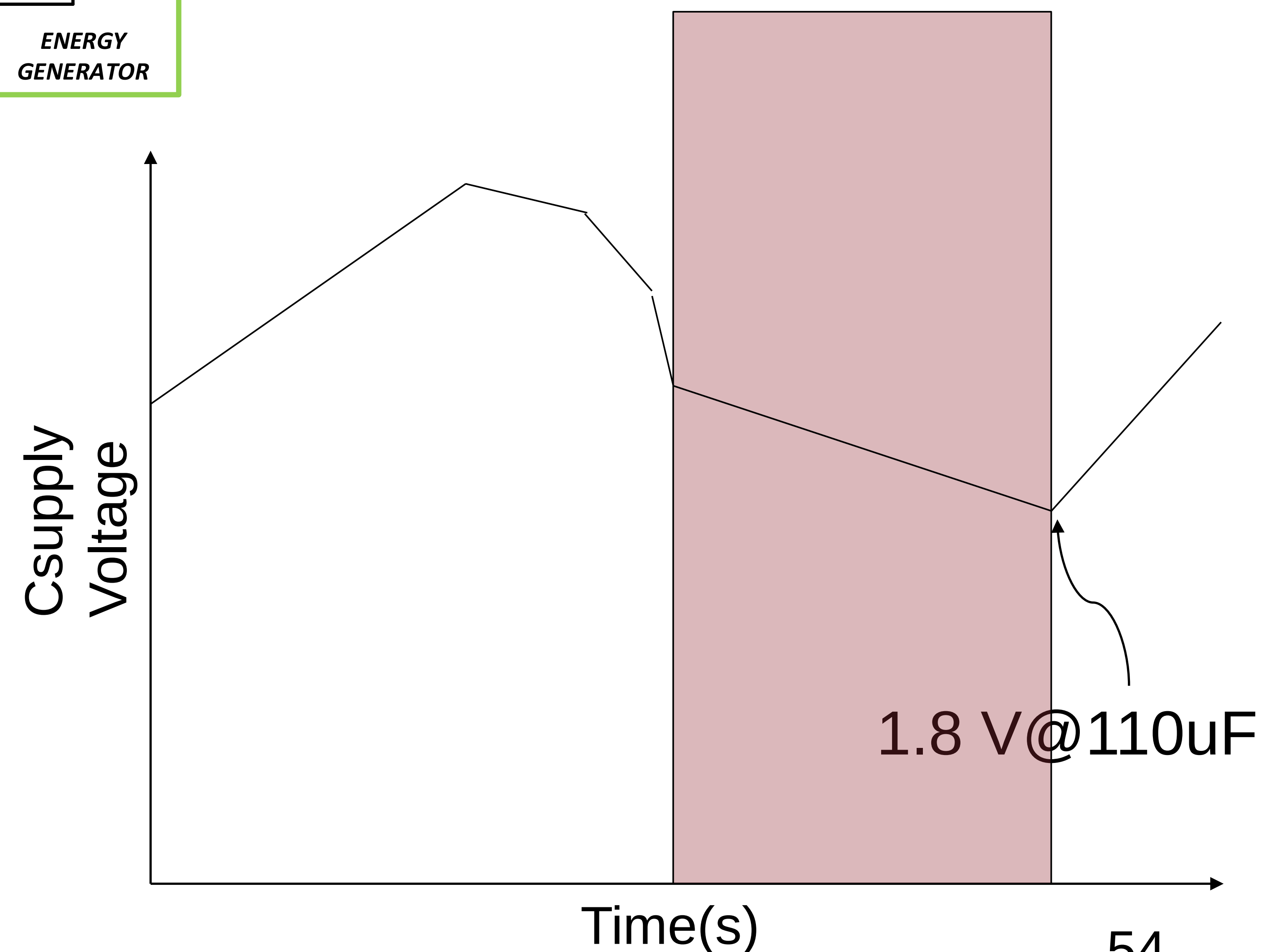
- The voltage monitor enable the LDO which supplies the communication module and sensor. Both element do their action as discharge the capacitor.



Key aspects of energy limited designs
Power management strategy

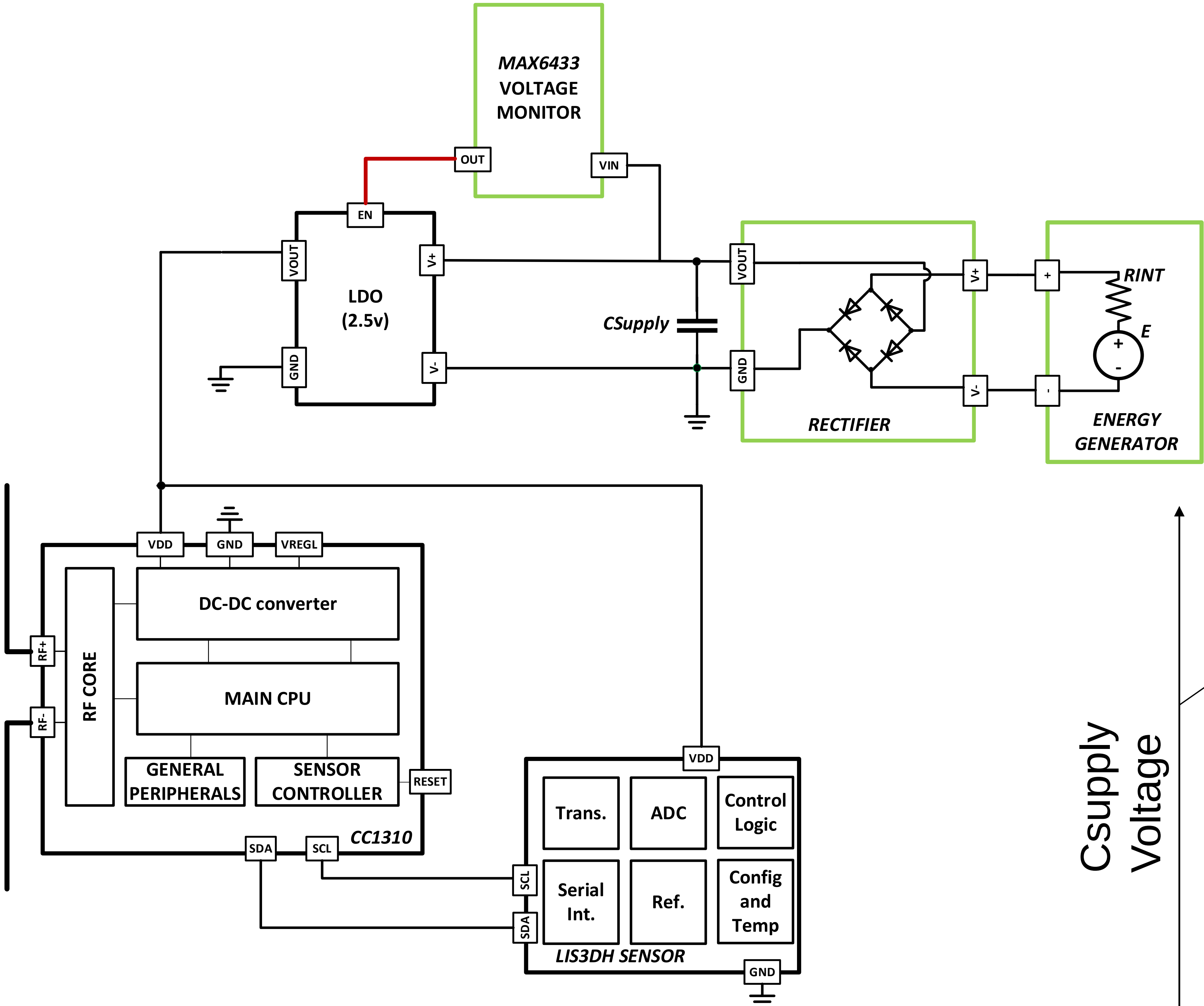


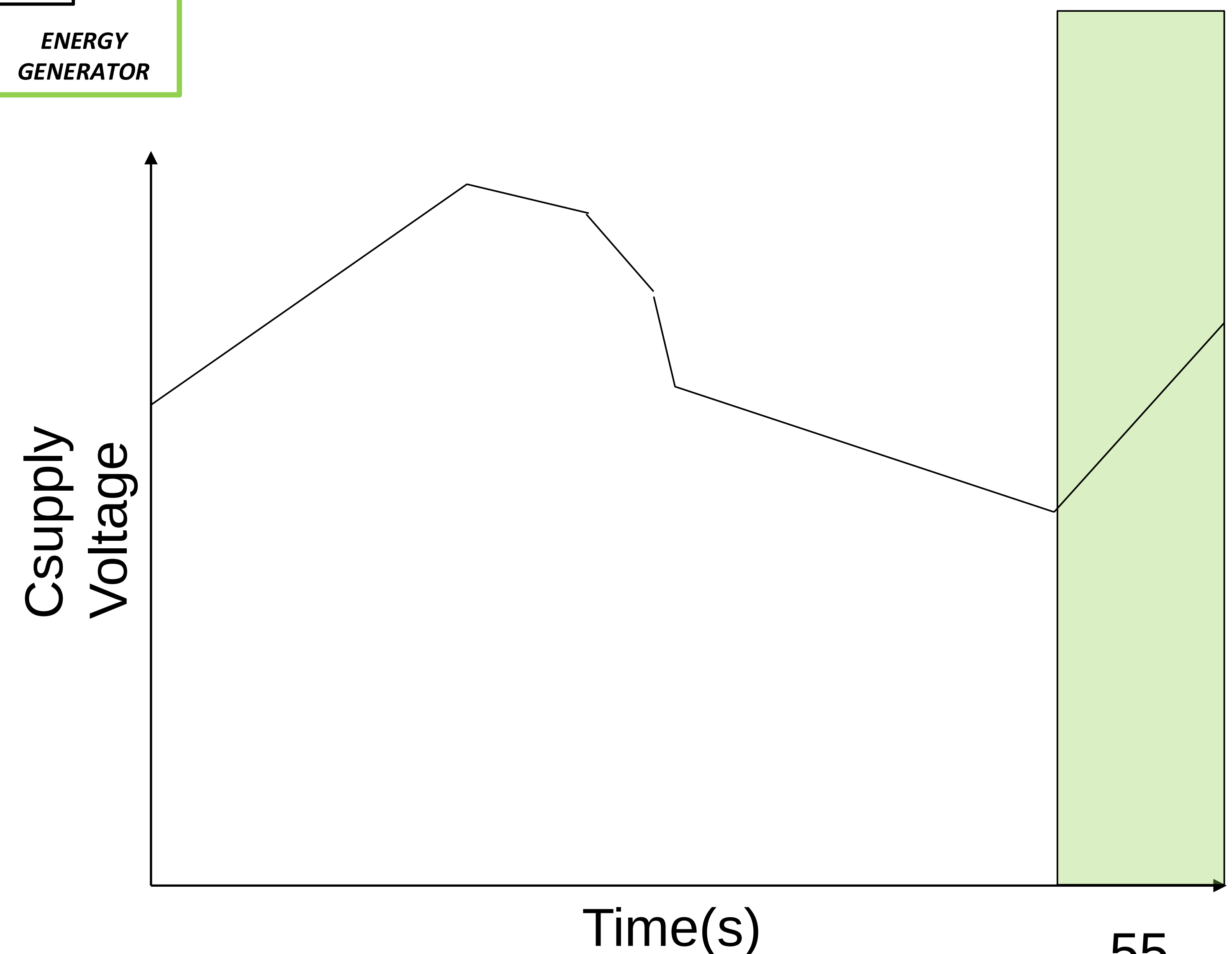
- As the voltage monitor is configured between 1.8V and 2.5V, the communication module and sensor sink current until Csupply voltage is reduced up to 1.8V.



Key aspects of energy limited designs
Power management strategy

- The LDO is disabled by the voltage monitor and communication and sensor modules are hardly switched, repeating the procedure.



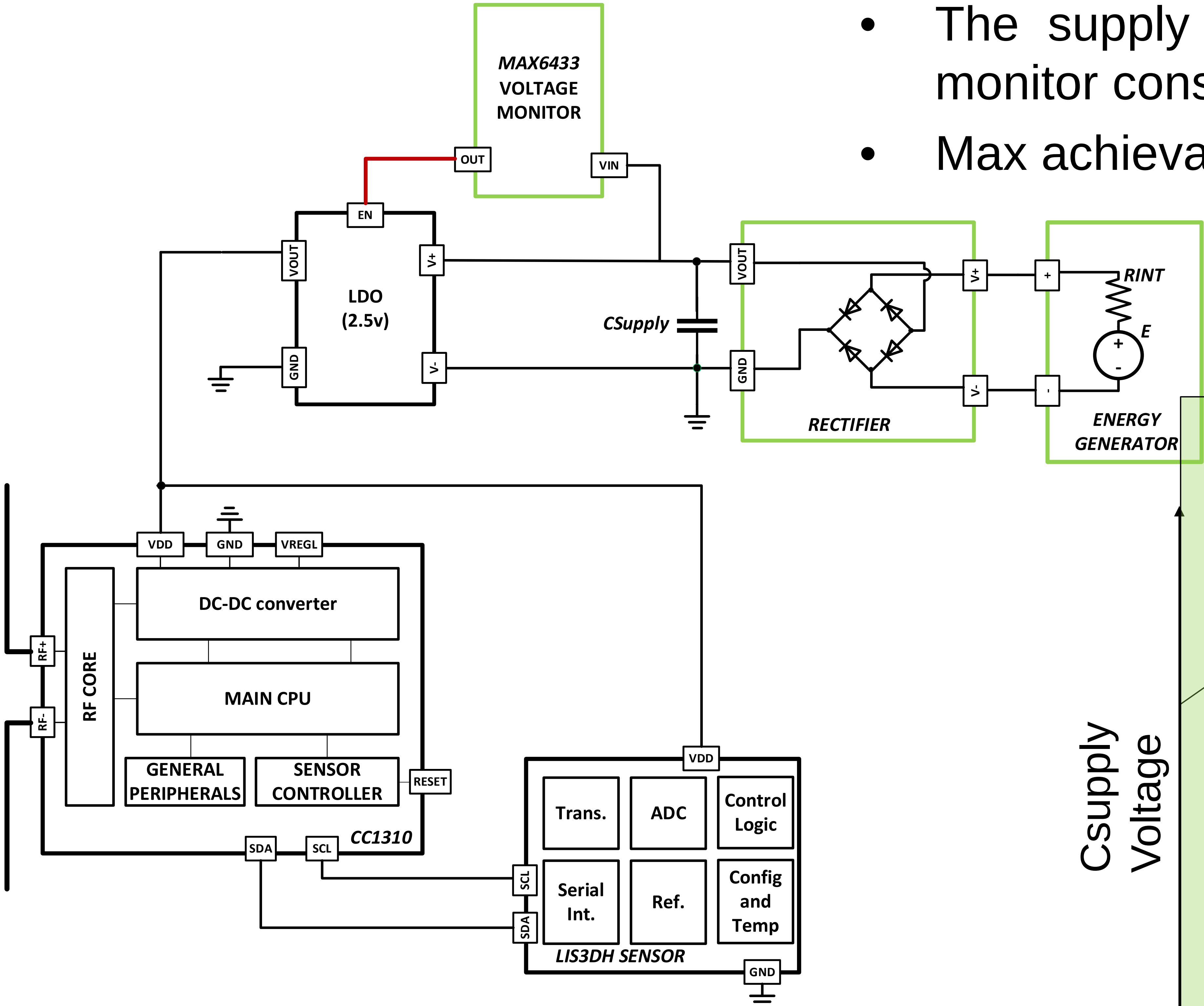


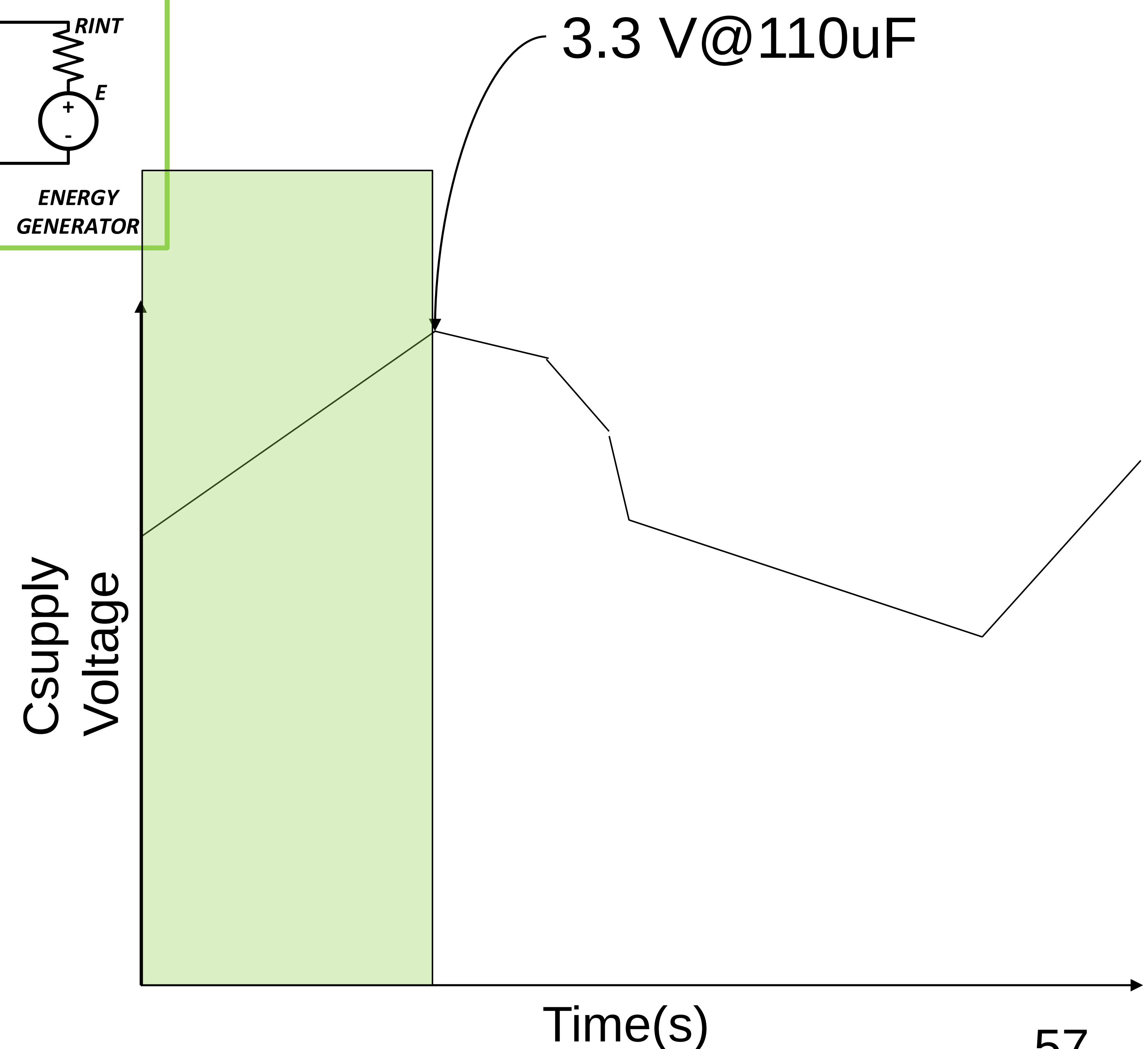
Key aspects of energy limited designs
Energy management and harvesters

- Is it possible to load a 110uF capacitor with 3.3V using an environmental harvester? Depends on:
  - The energy generator and its excitation. -> **I am just the electronic guy ☺**
  - The correct power management strategy.-> **Not challenging, but requires good knowleadge of the load.**
  - The resistive load that the voltage monitor represents.
  - The time that we have for doing so. Is it critical?

Key aspects of energy limited designs
Monitor resistive load

- The supply capacitor will charge as far as the monitor consumes less power than the generated.
- Max achievable energy determined by that.



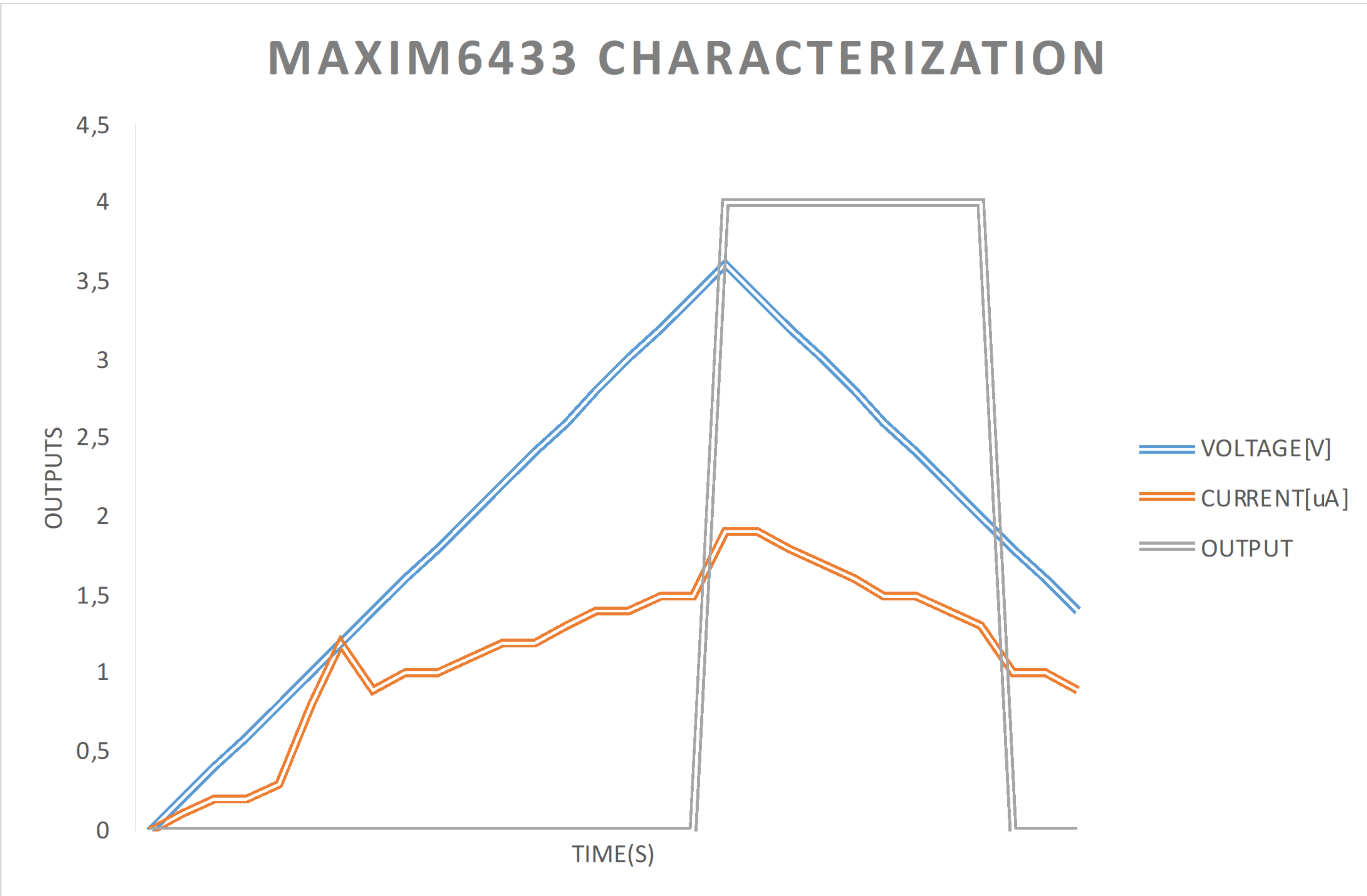


Key aspects of energy limited designs
Monitor resistive load

19-2323; Rev 2; 12/05

MAXIM

Low-Power, Single/Dual-Level Battery Monitors with Hysteresis



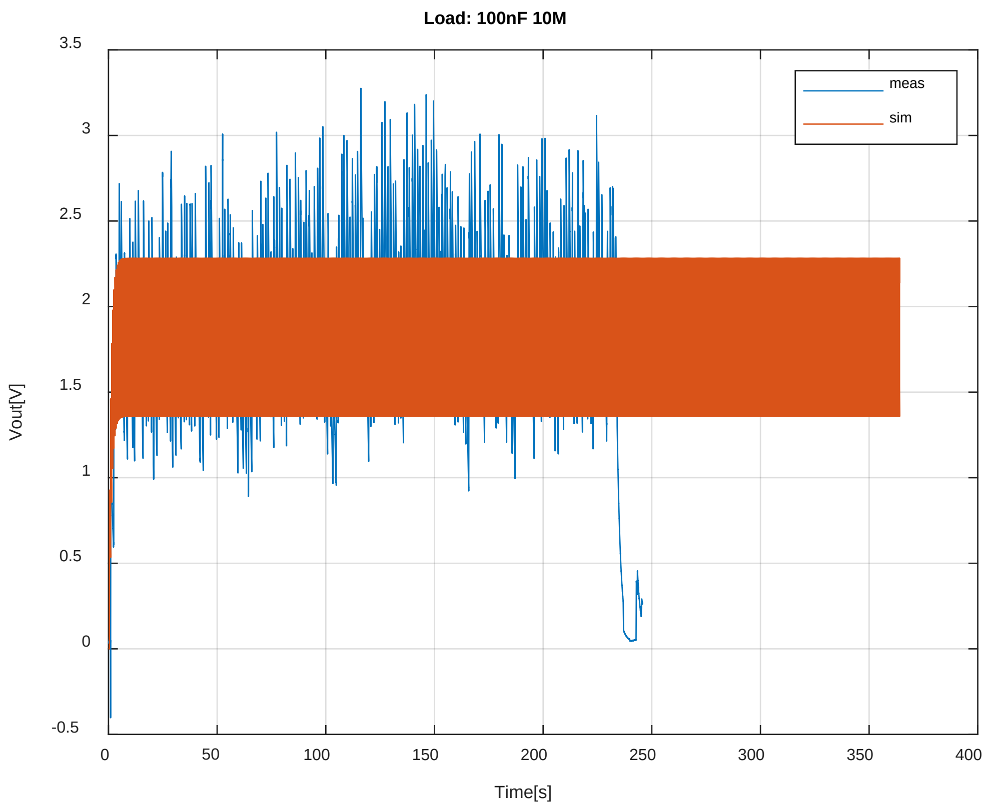
- Best in the market in subthreshold region.
- "Equivalent" to 1MΩ.

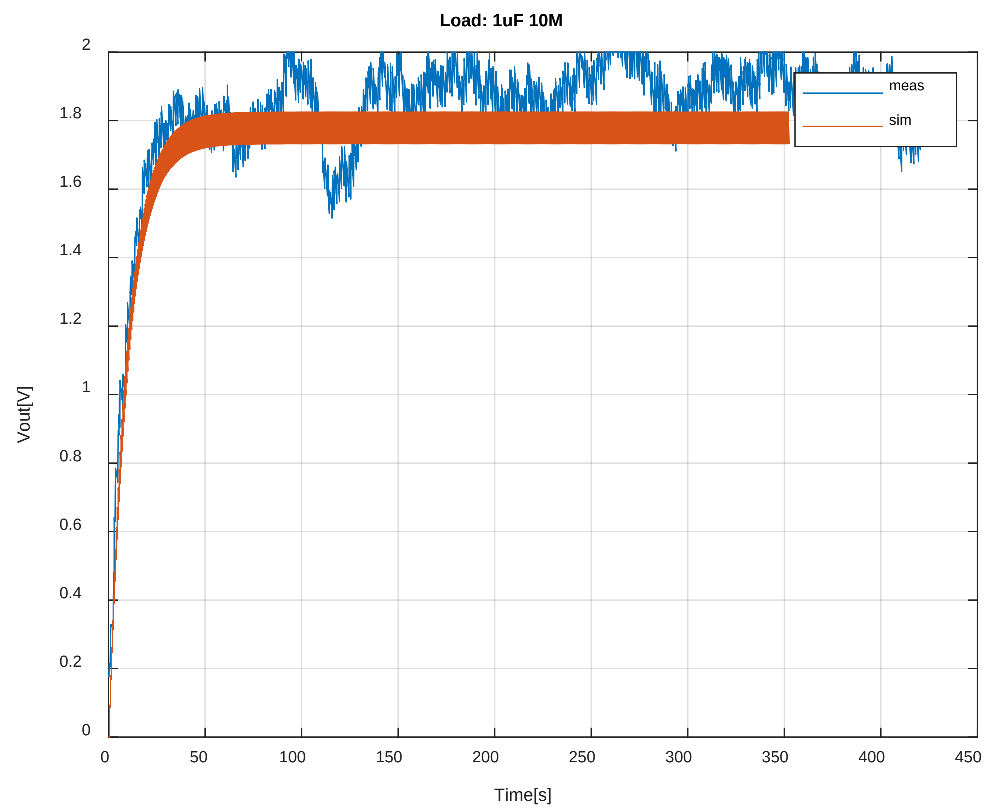
Features

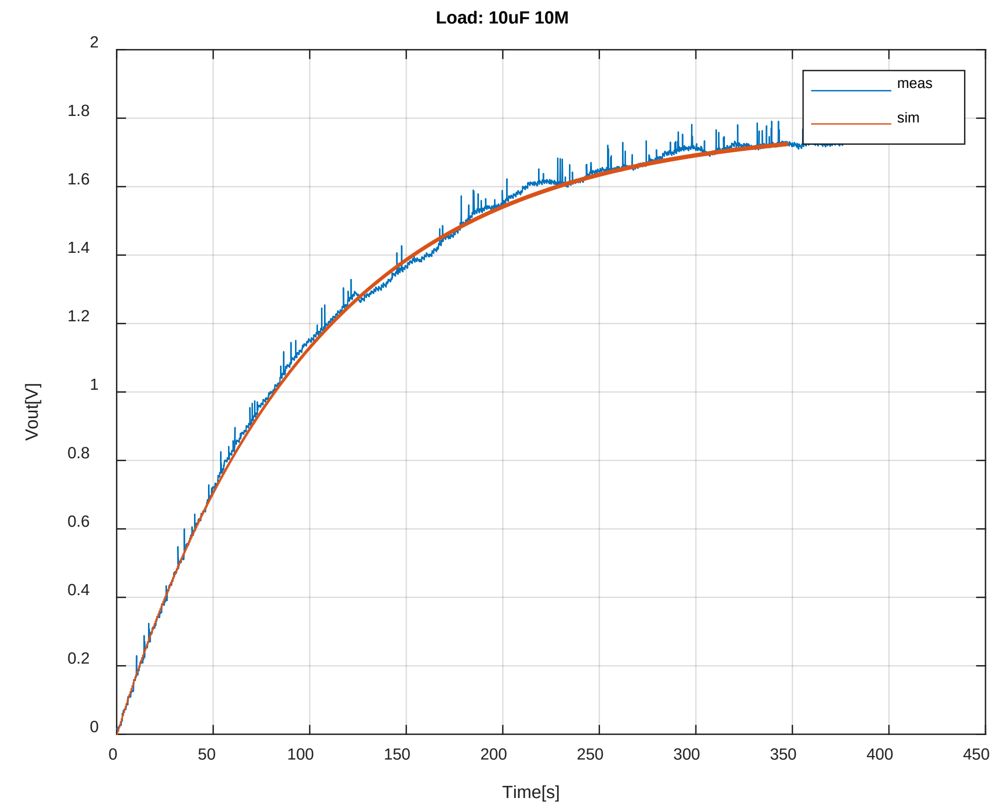
- Factory-Trimmed or User-Adjustable Threshold Options
  - Factory-Trimmed Low Thresholds from 1.6V to 2.1V or 2.6V to 3.1V in 100mV Increments (MAX6427–MAX6432)
  - Factory-Trimmed High Thresholds from 2.3V to 2.6V or 3.3V to 3.6V in 100mV Increments (MAX6427–MAX6432)
  - User-Adjustable Low/High Thresholds with 615mV Internal Reference (MAX6433–MAX6438)
- Low Current (1µA, typ)
- Single or Dual Low-Battery Outputs
- Push-Pull $\overline{\text{LBO}}$, Open-Drain $\overline{\text{LBO}}$, and Open-Drain LBO Options
- 140ms Minimum LBO Timeout Period
- Immune to Short Battery Voltage Transients
- Guaranteed Valid LBO Logic State to BATT = 1.0V
- -40°C to +85°C Operating Temperature Range
- Small 3, 4, 5 and 6-Pin SOT Packages
- No External Components Required (MAX6427–MAX6432)

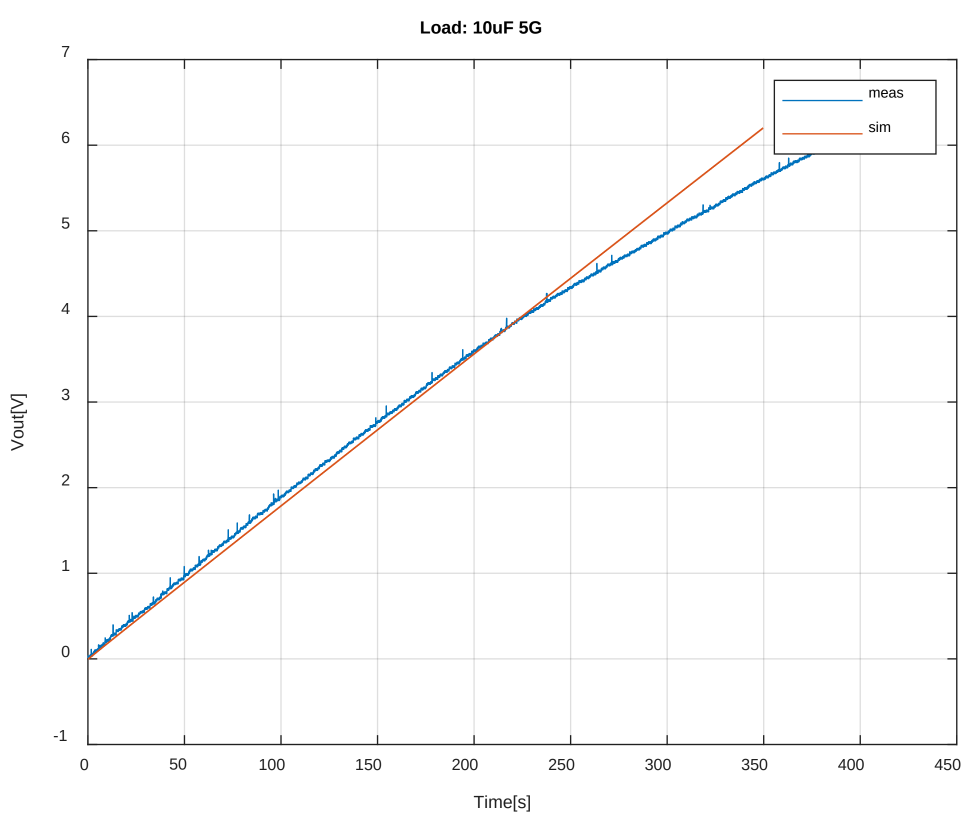
MAX6427–MAX6438

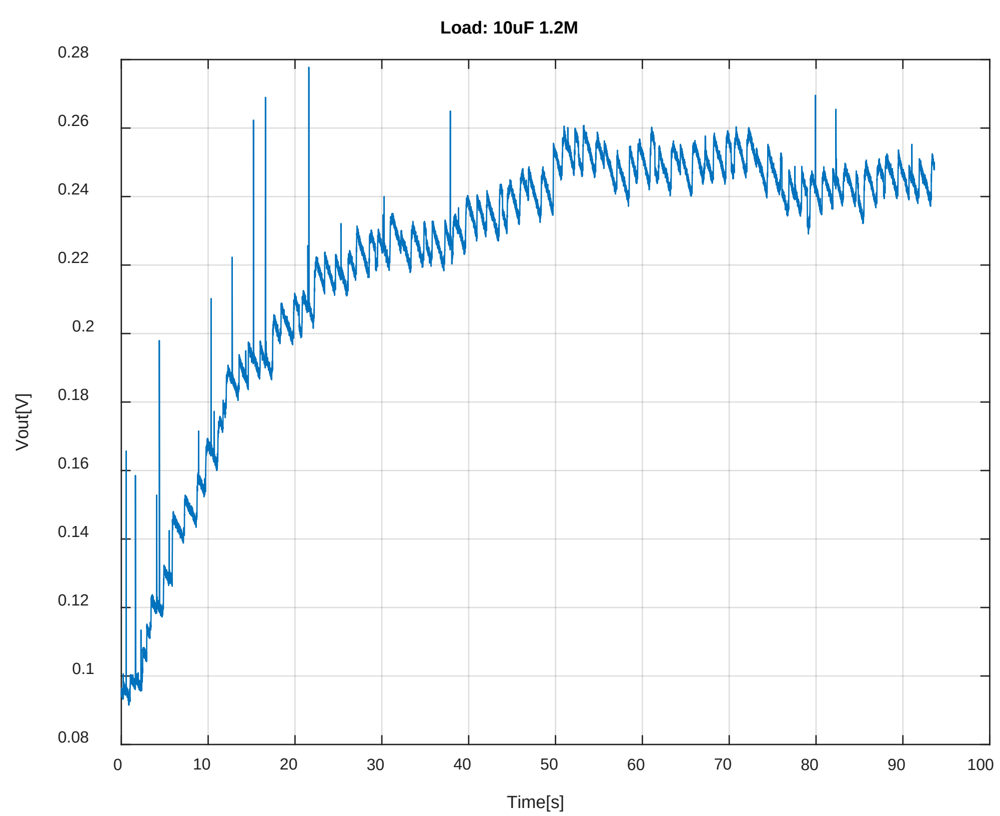
Key aspects of energy limited designs
Monitor resistive load











Resistor value-> critical in terms of maximum reachable voltage.
In this set-up->Should be around 10M-> equivalent to 100nA at 1V.

Capacitor value –> critical in terms of raising time.
Maybe not critical?

Key aspects of energy limited designs PMUs

- Sometimes the voltage monitor is inside a whole PMU, that includes the rectifier, charge pump and other features.

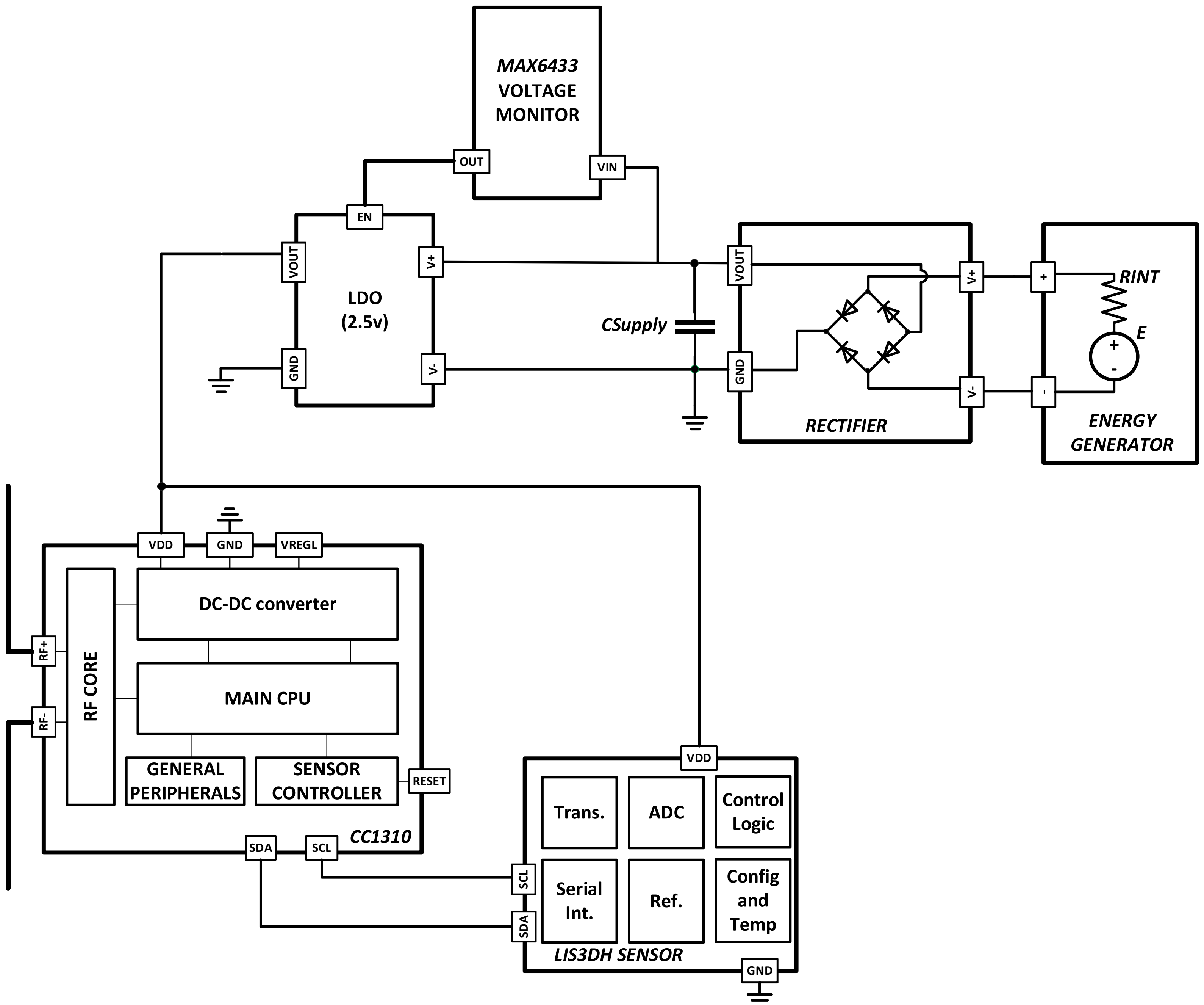
- The minimum input power of each device can be considered as the minimum power that the harvester needs to generate in order to start charging the capacitor.

Company	Model	Harvester type	Minimum input power [uW]
Analog devices	LTC3588-1	AC	500nA @ 3V
Texas Instruments	BQ25570	DC-ouput (TEG, solar, etc)	15uW to wake up 500nA later
E-PEAS	AEM30330	Vibration	3
E-PEAS	AEM0030	Impulse energy	3
NOWI	NH16D3045	Multi-source	10
NOWI	NH2D0245	DC-ouput (TEG, solar, etc)	3
XIDAS	EHM-UNIV-1	Multi-source	6

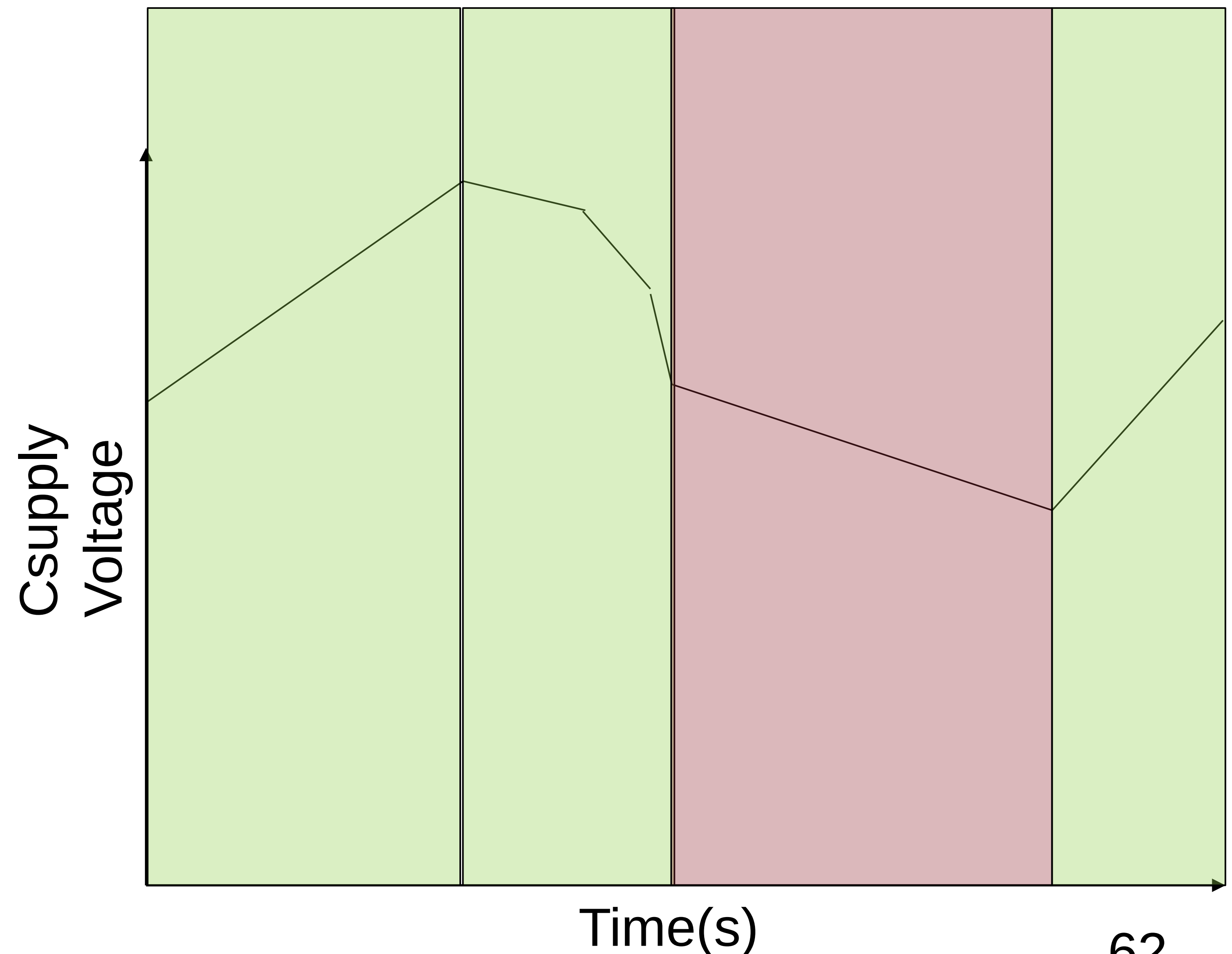
Key aspects of energy limited designs Energy management and harvesters

- Is it possible to load a 110uF capacitor with 3.3V using an environmental harvester? Depends on:
  - The energy generator and its excitation. -> **I am just the electronic guy ☺**
  - The correct power management strategy.-> **Not challenging but requires good knowledge of the load.**
  - The resistive load that the voltage monitor represents-> **Limiting factor regarding maximum reachable energy.**
  - The time that we have for doing so. Is it critical?

Key aspects of energy limited designs
Loading time



- Once that we ensure that the harvester generates more power that the consumed by the monitor, obtaining the desired energy is just a matter of time.
- It depends on almost every aspect of the design.



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  - The correct power management strategy.-> **Not challenging but requires good knowleadge of the load.**

  - The resistive load that the voltage monitor represents-> **Limiting factor regarding maximum reachable energy.**

  - The time that we have for doing so. Is it critical? **Depending on every aspect of the system. Harvesting energy is just a matter of time.**

Outline

- Autonomous wireless sensor nodes in IoT.
- Power limited VS Energy limited scenarios.
- Key aspect of energy limited systems.
  - Communication protocols.
  - Sensors.
  - Power generators and Energy Management.
- **Summary and future challenges.**

Summary and future challenges

- If we want to take out the battery we have two options:
  - If (harvested power>load power consumption)-> standard low power design.
  - If (harvested power<load power consumption)-> energy limited design

- Energy limited design:
  - Hardly switched off load during charging time. No activity.
  - 0 level QoS and/or simplex communication ->beacon mode.
  - The measurement + transmission is done whenever there is enough energy, no time based.
  - Really key to know if our application can adapt to this scenario.
  - The design challenge is not only the minimum power consumption but minimum energy (data rate paradox).
  - Determining and minimized energy budget really important.

Summary and future challenges

- Long and short range wireless sensor nodes without batteries are realistic with communication technologies such as BLE or sub 1GHZ custom protocols.
  - 40uF with 3,3V for the sensor.
  - 70uF with 3.3V for the communication module.
- Under these premises several devices have been developed.
- In order to continue advancing we have the following challenges:
  - Improve energy generators.
  - Reduce the energy requirements of sensors and communication modules.
  - Develop ultra low-current consumption voltage monitors. Personal objective- <100nA.
  - Introduce the “capacitor charging” objective as design criteria for the energy generators and PMUs (not the MPPT).
  - Promote this “energy limited” concept in the research and industrial world.

ENERGY LIMITED COMMUNICATIONS IN HARVESTER ASSISTED WIRELESS SENSOR NODES

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ISOCS Winter School 2023